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ABSTRACT

A nine-day study was designed to investigate the learning achievement differences between paired and individual high school students in a Computer Assisted Instruction course in Boolean Algebra. Within the format of five 40-minute lessons (including preview frames, instruction, examples, practice problems, criterion frames, and daily quizzes), 23 concept units were developed. Thirty-six of the 54 participating students were paired for all activities except the final examination; the remaining 18 students participated individually. Data collected included results of various pre-course algebra knowledge tests, preview questions, criterion questions, daily lesson quizzes, the final examination, and attitude questionnaires. Analyses (which included reliability estimates, the F test, and correlation coefficients) of results showed no significant differences between the two groups in post-course achievement or in individual concept unit scores, indicating that paired instruction using CAI techniques is as effective as individual instruction. Further investigations are indicated as a result of the study into paired versus individual achievement, the pairing variable, student controlled instruction, task difficulty, and pair-individual alternation. (SP)

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CAI CENTER

TECH REPORT

INDIVIDUAL VERSUS PAIRED LEARNING OF AN ABSTRACT ALGEBRA PRESENTED BY COMPUTER ASSISTED INSTRUCTION

Technical Report 5

William P. Love

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
OFFICE OF EDUCATION

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ABSTRACT

INDIVIDUAL VERSUS PAIRED LEARNING OF AN ABSTRACT ALGEBRA PRESENTED BY COMPUTER ASSISTED INSTRUCTION

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The use of paired learning teams was investigated as a possible technique for improving instructional achievement and efficiency. The primary question was the comparison of achievement of students who learned in pairs with the achievement of students who learned individually, all subjects being tested independently and instruction presented by means of an IBM 1500 CAI system. Fifteen subsidiary questions were investigated including comparison of error rates, various timing measures, and confidence ratings. Also investigated were the pair-formation variables, the nature of paired interaction, and variations of task difficulty.

Fifty four basic algebra students were divided into 18 pairs and 18 individuals, where paired partners were selected by mutual choice. The two groups took a five lesson Boolean algebra program at the Florida State University CAI Center in the Spring of 1969. The program included a basic introduction to logic, set theory, and switching networks which were divided into 23 concept "units."

A preview question was given at the beginning of each concept unit, a criterion question at the end of the unit, a daily quiz was at the end of each lesson, and a final examination after completion of the program.

A comparison between the paired group and individual group on final examination scores revealed no significant differences in achievement. No differences were found on any of the seven time variables recorded although the paired group required less time on six of these measures. No differences were found in error rates, number of practice problems solved, criterion frame scores, or daily quiz scores. No differences were located between "successful" pairs and the individuals or the "other" pairs.

In conclusion, with instruction presented by CAI, the paired group learned Boolean algebra as well as the individuals in every respect. In addition, with two students instead of one at each CAI terminal, educational costs may be substantially reduced and system efficiency increased.

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The author happily dedicates this study to his parents who labored many years, and to Cissy who gave so much.

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CHAPTER I

BACKGROUND TO THE STUDY

Introduction

The general objective of this study is the development of a technique which will improve the effectiveness and efficiency of a computer assisted instruction system. The technique under consideration is the use of paired learning teams during instruction rather than the usual individualized instruction. In order to investigate this technique pairs and individuals are compared in several performance variables measured during and after participating in an instructional program. Therefore, in view of the general objectives, the primary purpose of this investigation is the comparison of the achievement of students who learn in pairs with the achievement of students who learn independently, all subjects being tested individually and instruction presented by means of the 1500 CAI system. Although studies of paired learning appear frequently in the literature, no study has been conducted comparing paired and individual learning utilizing the most recently developed computer assisted instruction system currently in use at the Florida State University Computer Assisted Instruction Center.

Some subsidiary questions which are investigated include: How do pairs and individuals compare in total instructional time required? How do pairs and individuals compare in the number of errors made when answering questions during the instruction?

Can experimental evidence be collected which clarifies the nature of the interaction between pair members? How do pairs and individuals compare in achievement, time needed, and number of errors when learning memorization materials and problem-solving materials?

Preliminary Terminology

In order to review research on small group instruction, it is important to distinguish types of groups described in the literature. Lorge, Fox, Davitz, and Brenner (1958) define three distinct small groups.

An ad hoc group is usually assembled for the purpose of experimentation. Its members are most often strangers with little in common other than participation in the experiment. An ad hoc group does not have established patterns of interaction.

A traditioned group, on the other hand, probably existed prior to the experiment. Its members are close friends with established patterns for working together for mutual goals. A traditioned group functions together efficiently as a team.

A nominal group does not exist in the physical sense of the word since its members never come in face-to-face contact or engage in interaction with each other. A nominal group consists only of the statistical pooling of a group of individuals who all work independently of each other. Their combined efforts are treated as if they were a group. For example, suppose an investigator was comparing a nominal group and a traditioned group in their ability to solve a given problem. The traditioned group works together collectively trying to solve the problem. In the nominal group, each member works on the problem independently without communicating with the others and if any one member solves the problem, then it is scored for the nominal group.

Ad hoc and traditioned groups are considered real groups since their members actually communicate with each other, while a nominal group is not a real group in that there is no communication.

Previous Research Comparing Achievement of Subjects Who Learned in Groups with Those Who Learned Individually

The literature does not contain any studies which investigate the technique of paired learning teams during instruction using the modern 1500 CAI system. Therefore, the present study is unique in this sense. Many studies have been conducted which provide insights on the nature of paired instruction, which illustrate difficulties to be avoided and which provide results to be compared with the results of this experiment.

A large number of investigations comparing small group achievement and individual achievement for many types of tasks are found in the literature. In order to examine some of these studies, it is necessary to distinguish between various methods used in making comparisons between groups and individuals.

"Group product" will be understood to mean any measure of achievement or performance, such as scores, grades, ranking, or the number of correct solutions made by the group working collectively.

The three types of comparisons are:

1. group product vs. individual product
2. group product vs. nominal group product

3. individual product when learned in group vs.
   individual product when learned independently

Many earlier investigators found that group achievement was superior to individual achievement (Barton, 1926; Shaw, 1932; Thorndike, 1938; Husband, 1940; Klugman, 1944). These studies were primarily of the first type, comparing a group produce against an individual product. A typical example was Shaw (1932) who compared the number of problems solved by quads and individuals. She found 53 percent of the solutions turned in by groups were correct while only 7.9 percent of the solutions by individuals were correct. Her conclusions obviously found groups superior.

Because these eariler investigators found the group product superior to the individual product, they concluded that groups learned better. However, later investigators found this conclusion invalid. They showed that groups would always obtain superior scores on performance measures simply as a result of the combined effort of the individuals in the group. The probability that at least one member in the group would know how to solve a particular problem was always greater than the probability that any given individual would know how to solve it. Thus groups were always favored statistically due to the pooling of knowledge. This discovery cast doubts over the conclusions of the earlier investigations.

The next generation of investigators contrasting individual and group performance used the second type of comparison (Marquart, 1955; Faust, 1959; Anderson, 1961; Hall, Mouton, & Blake, 1963). These studies eliminated the statistical inadequacies found in the earlier investigations by comparing real group products against nominal group products. For example, Marquart (1955) used shaw's data for his experiment. When he analyzed the data using the old methods, the groups were significantly superior. When he re-analyzed the data comparing her group scores against nominal group socres (pooling of individual scores into a single score), there were no significant differences.

The comparisons between groups and individuals which correspond best to real life situations are of the third type. In this case, students learn either independently or in groups, but all are examined individually (Hudgins, 1960; Banghart, & Speaker, 1963; Dick, 1963; Grubb, 1965; Hartley, & Cook, 1967; King, 1967; Noble, 1967). This experiment adopted the third type of comparison, hence these investigations are discussed in more detail.

Hudgins (1960) used 128 fifth graders to compare individuals and quads in solving arithmetic problems from the Stanford Achievement Tests. Upon testing the subjects individually, he found no significant differences between the scores of those who studies in quads and those who studied alone. He concluded, "These findings indicate that, although groups of students working cooperatively solve more problems than comparable students working alone, there is no significant improvement in problem solving performance of the former Ss because of this group experience (P. 40)." Hudgins' investigation provides some insights on learning within small groups although not learning pairs. Lorge et al. (1958) indicates that learning effectiveness decreases as the number of members in a small group increases, hence pairs represent the ideal size learning team, not quads. Also in this study, instruction is presented by pencil and paper. Do the same results apply when materials are presented by CAI?

Banghart and Speaker (1963) examined the creativity of 180 seventh graders when working mathematics problems from the SMSG test, Number Systems. They compared groups and individuals to determine the role of group influences upon creativity in mathematical problem solving, but found no significant differences when all subjects were tested individually. They concluded, "In none of the research studies completed did the group factor make any contribution to problem solving. On the contrary, there seems to be a consistent, if slight, advantage to solving problems alone (p. 257)." These authors did not mention exactly what type of "groups" were used in their study. Although this study investigated the creativity of students solving mathematics problems, the present study examines a number of different performance variables and achievement both during and after completion of an instructional program.

Dick (1963) compared 70 university students when learning college algebra in pairs and singly. The materials were presented by programmed texts. He concluded, "The results of the group performances on the midterm and final examinations, the tests of transfer, and the total daily unit-test points indicate no significant differences [between pairs and individuals] at the .05 level (p. 45)." There are several important differences between Dick's study and this investigation. He used random assignment into pairs, thus procuding ad hoc groups of strangers. There is some evidence that ad hoc groups derive the least benefits from interaction while traditioned groups gain the maximal advantage. This conjecture is supported by the conclusions of Husband (1940) who found that pairs of friends perform much better than pairs of strangers. Another difficulty in Dick's study was his experimental constraints upon the pairs.

> The students who worked in pairs were told that they should sit side-by-side with the program placed between them; that they should read the first frame and write their answers [without discussion] on their own individual answer sheet. When both students were finished with a frame, the mask was moved down the page to reveal the correct answer. If both students were wrong in their answer, they were instructed to check over the item and discuss the material in the frame until both members were satisfied they understood it (p. 40).

This method appears to eliminate a large portion of the interaction and creates unreal restraints upon the pairs. The students often complained about this procedure. The present study differs from Dick's study in the use of a CAI presentation rather than programmed texts. It also attempts to eliminate some of the weaknesses in his study related to the method of forming pairs and the nature of their interaction. In the present study the pairs approximated traditioned groups rather than ad hoc groups and all restrictions imposed upon interaction between partners was eliminated.

Klausmeier, Wiersma, and Harris (1963) compared individuals, pairs, and quads of educational psychology students in their ability to determine certain patterns during card presentations. They were primarily interested in the amount of transfer to individual performance after training within the groups. They conclude,

> Pairs and quads accomplished this [deduced patterns on cards] better collectively than did individuals working alone; however, not all the members of pairs and quads learned well. When on their own and working individually on the transfer problems, they could not apply, for they had not learned (p. 164).

Their investigation differs from this study in that it used ad hoc groups (random assignment), unrealistic learning materials (deducing patterns on cards), and different presentational media (flashcards).

Hartley and Cook (1967) compared the performance of twelve and fourteen year-olds when learning in the mathematical programs Directed Numbers, An Introduction to Graphs, and Simple Equations. Students were paired by mathematical ability (high or low) into homogeneous pairs (HH and LL) or heterogeneous pairs (HL). Comparisons of final achievement were made between H and HH, L and LL, H (alone) and H (in HL pair), and L (alone) and L (in HL pair). They found no significant differences between the H and HH, L and LL, or H (alone) and H (in HL pair) scores. In comparing L (alone) and L (in HL pair), however, they found the low member of the HL pair performed worse. Their investigation differs from the present study in that pairs were formed according to mathematical ability creating ad hoc groups which do not benefit most from pairing. Do the results discovered when using programmed text presentation also apply when using the modern CAI system? The investigators admitted the small number of subjects (22 total) could have biased the results.

Noble (1967) compared the achievement of twelve pairs and twelve individuals after completing an Auto-Tutor presented trigonometry program. Pairs were formed by mutual selection of partners (this was the only study found by this author which used this method of pairing). The subjects worked in the experiment for one hour per week for a total of eight weeks. He concluded,

> There appeared at first to be no significant differences between the groups, but a more detailed examination showed

> the paired group to have fared significantly worse when answering the more difficult questions than the group who worked on their own (p. 108).

The major weakness in Noble's study was that subjects worked together only one hour per week, which is not sufficient time to develop working routines, patterns of communication, and teamwork which are the primary advantages of paired learning. Do the conclusions found using Auto-Tutor also apply to CAI?

The investigation most relevant to this study was conducted by Grubb (1965), who compared ten individuals and ten pairs of college students when learning statistics. This study was the only one located by this author in which the materials were presented by means of computer assisted instruction. His subjects were classified as high or low (H or LO on the basis of CEEB verbal scores, then formed into HH or LL pairs. He compared the final exam scores of the H subjects against the HH and the L subjects against the LL, where all members were tested individually. He observed, "The analysis indicated there is no significant difference in final exam performance between any of the treatments in this study (p. 5)." He also recorded the instructional time and error rates, finding no significant differences between pairs and individuals in instructional time. There were no differences in error rates between high pairs and high individuals, but low pairs made significantly fewer errors than low individuals. His investigation differs from the present study in several respects. Grubb used pairs formed on the basis of CEEB verbal scores, hence his pairs were ad hoc groups of strangers rather than traditioned groups. Another difference is the nature of the presentation media.

His study used a computer-controlled typewriter (1440) which is now considered inefficient and obsolete. The newer CAI system (1500) includes a television screen (CRT) and typewriter at the student terminal. This more recent system differs from the older system in four important aspects: (1) timing, (2) response mode, (3) physical characteristics, and (4) the recording capability. The older 1440 requires much more time to present materials than the newer system. Instructions and information are typed on a computer print-out sheet. Students tend to become bored and frustrated while waiting for this typing since the machine types much slower than most students read. They often feel the machine slows them down rather than helping them learn faster. The newer 1500 system, on the other hand, displays materials rapidly, and the students have little chance to become bored. The student responses on the 1440 system are entered by the typewriter keyboard. This means that one student must become the typist while the other remains relatively passive. The 1500 uses light-pen as well as keyboard responses, thus both members may point to the screen and participate equally in the learning process and eliminate the active-passive duality. The physical characteristics of the 1440 make paired instruction slightly more difficult on that system since the print-out is harder to see than the CRT screen on the 1500. One important difference between the 1440 and 1500 systems is the recording capability. The 1440 provides a typed record of all material presented in the program including the student responses. If a student wants to look back over previous materials, he can easily refer to the recorded print-out from the typewriter. The 1500 does not have this particular advantage, hence there is no way a student can review materials or refresh his memory. Since the newer system does not have a record of previous materials and responses available to the students, they must rely totally upon their ability to remember. Pairs may be superior in recalling past information and as a result obtain higher achievement when using the 1500 system.

All these studies have found no significant differences between the achievement of those who learn in pairs and those who learn individually. There may be three explanations for these results. One possibility is that there is actually no advantage in learning within pairs. A second possibility is that the learning tasks investigated within the literature may not elucidate the advantages of paired instruction. The third possibility is that recording instruments and testing devices may not have been sensitive enough to detect the superiority of paired learning. This author leans toward the last two possibilities.

To summarize, the present study investigated the use of paired instruction as a technique to improve the efficiency and effectiveness of CAI. This was accomplished by comparing the achievement of pairs with the achievement of individuals and by simultaneously examining the nature of learning within pairs. There are several factors which make the CAI system a superior tool for paired learning research. Using this device it was possible to collect certain performance data which was virtually impossible to obtain by any other means. Also, the recorded data are accurate, reliable, and totally unbiased. Although the literature contains studies which provide insights and conclusions related to the present study, the technique of paired learning utilizing a CAI system had not been satisfactorily investigated.

Previous Research Comparing Subsidiary Factors Related to Performance of Subjects Who Learned in Groups with Those Who Learned Individually

The previous research may be classified into three general areas: time factors, type of instructional task, and nature of paired interaction. Within each of these general areas are a number of specific questions to be investigated.

Some of the questions examined in previous studies were re-examined in this experiment utilizing a CAI system, while other questions were included which had never been examined to the knowledge of this author.

Final achievement in a learning task cannot be viewed independently of the time variable. Do pairs require more time than individuals when learning by means of the newer CAI system? Learning rates become particularly important when computer and personnel schedules are taken into consideration. A few studies have compared the learning rates of pairs and individuals. Dick (1963) found it took 27.3 hours for individuals to complete the algebra program, while the pairs required 29.0 hours. Although this difference was statistically significant, he noted that it was of little practical significance. Again, his experimental restrictions may have minimized any real differences for naturally interacting pairs. Grubb (1965) found no significant differences between the time required for pairs and individuals to complete the computer-presented statistics course.

Any real differences between the learning rates of pairs and individuals may have been undetected because of the relatively slow presentation and processing of the older 1440 system. Learning rates using unrestricted interaction and faster presentation media have not been compared for pairs and individuals.

A second subsidiary question related to paired instruction is the nature of the task learned. Intuitively, one would believe that paired instruction offers no advantage when the learning task is relatively simple, but when the learning task becomes very difficult, then the advantages of pairing become noticeable. Sawiris (1966) comments,

> . . . although some forms of group learning proved to be quite effective, there are two main factors that marred and minimized such effectiveness. The first is the task used. An easy task such as a program designed for individual use will tend, by limiting the interaction between members, to hide the effects of the group (p. 146).

Pairs and individuals have been compared using a wide range of learning tasks. The mathematical tasks mentioned in the literature include solving first-year algebra problems, solving elementary arithmetic problems, solving problems in symbolic logic, learning number systems, learning elementary number theory, learning elementary trigonometry, learning college algebra, and learning statistics. Thorndike (1938) and Husband (1940) found pairs achieved better for more difficult tasks, while Noble (1967) found pairs performed significantly worse when answering the more difficult problems. The author has not located any investigation which carefully investigates the question of performance related to task difficulty using mathematical materials. The Boolean algebra program provides problems with a moderate range of difficulty, hence this question was examined. The materials in the program are divided into two types of learning tasks: memorization tasks and algorithmic tasks (see Instructional Materials).

A third subsidiary question related to paired learning concerns the interaction between members during the learning process. Many claims are made in the literature about the nature and process of the interaction of a learning pair, although little conclusive evidence has been produced. According to Hartley and Cook (1967), "It is difficult to observe exactly what happens when students learn in pairs and more research needs to be done on this."

One claim is that pairs make fewer errors during the learning process since members carefully examine the suggestions made by their partners and reject most incorrect options (Shaw, 1932; Thorndike, 1938; Grubb, 1964). Shaw observed,

> Groups seem assured of a much larger proportion of correct solutions than individuals do. This seems to be due to the rejection of incorrect suggestions and checking of errors in the group.

Only two studies found by this author determined the error rates for groups and individuals. Moore and Anderson (1954) found no significant differences in errors made by trios and individuals in solving problems of symbolic logic. Their investigation determined the error rate while the subjects attempted to solve problems which were presented without previous instruction while the present study examined the number of errors made during the process of instruction. Grubb (1964), using the 1440, found little difference between the errors of high pairs and high individuals, but low pairs reduced their errors by 25 percent and at times by 50 percent compared to low individuals. Since the 1440 system includes a printed record of the student responses, one can easily look back at earlier answers and prevent repeated errors. This capability suggests that fewer errors would be made on the 1440 system than on the newer 1500 system. The present study investigated this question further.

Another claim is that pairs in intense interaction are able to generate new ideas, insights, and knowledge which neither of the members possessed prior to working in the team (Tuckman, & Lorge, 1962; Hall et al., 1963). Counter to this, others claim that paired interaction is nothing more than a pooling or summation of the background and knowledge which each member brings to the team and shares with his partner (Shaw, 1932; Taylor, & McNemar, 1955; Hudgins, 1960; Maurer, 1968). In essence, the question is whether group interaction is nothing more than a pooling and sharing of the individuals' knowledge or if group interaction is pooling with an additional benefit of the generation of new knowledge as a result of communication. This question is usually investigated by contrasting nominal groups with real groups (Marquart, 1955; Faust, 1959; Anderson, 1961; Hall et al., 1963). Of these, three found no significant differences between the performance of real groups and nominal groups, while Hall et al., found real groups superior. They concluded, "The present study indicates that interaction per se contributes something to group performance over and above the effects obtainable from bringing several individual judgments to bear on a common problem (p. 147)." It is the belief of this author that any differences between pooling only and pooling plus generation are very subtle. Most of the investigations of the question probably used comparison measures which were too insensitive to detect any differences. The recording capabilities of the computer and the instructional strategy of this study provide a unique and interesting technique for investigating this question more carefully (see instructional model).

Another claim is that in group interaction the process of communication, of confirming or discouraging, provides mutual reinforcement and increased confidence by the members, resulting in less internal anxiety and better performance (Thorndike, 1938; Hoffman, 1965, Parachini, 1968). A high correlation between a student's confidence in his answers and the correctness of his answers was reported by Massengill and Shuford (1967). This author believes that communication and interaction should produce higher confidence for pairs, and that higher confidence might result in better achievement. Do pairs actually feel more confident in their answers than individuals? This author has not located any studies which measure the confidence of pairs and individuals, thus the present study investigated this question by having subjects indicate their degree of confidence when answering selected questions in the program.

This study investigated sixteen specific questions related to the use of paired learning teams as an instructional technique. These included the primary question comparing the achievement of pairs and individuals and fifteen subsidiary questions related to the performance variables and the nature of paired instruction.

Questions Under Investigation

1. The primary question under consideration is the comparison of final achievement of students who learn Boolean algebra in pairs with students who learn individually when instruction is presented by means of the IBM 1500 CAI system and all subjects are tested individually.

Fifteen subsidiary questions suggested by the literature were investigated in this study including questions related to achievement, confidence, timing, number of errors, type of pair, nature of paired interaction, and types of learning tasks.

2. Does this instructional program provide any learning, that is, is there any increase in achievement for the pairs and individuals?

3. How do pairs and individuals compare in achievement when answering questions during the learning phase of the program?

4. How does achievement during the learning phase correlate with achievement during the examination phase for the pairs and individuals?

5. What are the results when pairs are allowed to work together in a combined effort on examinations?

6. What is the relationship between the achievement of both partners when they must perform independently? That is, do partners tend to answer given problems in the same manner or are their answers independent of each other.

7. How do pairs and individuals compare in various time measures including total instructional time and question latency time?

8. How do pairs and individuals compare in the number of errors made when answering questions during the instructional program? In what way are errors related to the other performance variables?

9. How do pairs and individuals compare in the confidence of their answers during the program?

10. How are confidence measures related to the other performance variables? (Performance variables include: number of problems answered correctly, preview and criterion frame scores, total instructional time, problem-solving time, preview and criterion latencies, preview and criterion confidences, and number of errors.)

11. Is there any experimental evidence which supports the claim that paired interaction consists of pooling of information and knowledge?

12. Is there any experimental evidence which supports the claim that paired interaction consists of a generation of new knowledge not possessed by either member prior to the interaction?

13. Assuming that certain selected pairs may be described as "successful pairs," how do these pairs compare with the individuals in the performance variables?

14. How do the "successful pairs" compare with the "other pairs" in the performance variables?

15. How do pairs and individuals compare in the performance variables for those materials in the program classified as "memorization tasks"?

16. How do pairs and individuals compare in the performance variables for those materials in the program classified as "algorithmic tasks"?

CHAPTER II

DEVELOPMENT OF THE PROGRAM

Computer Assisted Instruction

In 1958, I.B.M. Corporation realized the possible application of the computer as a teaching machine and developed the first computer assisted instruction system using an ancient IBM 650 computer to teach binary arithmetic. Since that time, CAI installations have spread throughout the world and some schools have begun operating full scale instructional systems. Basically, a CAI system consists of four elements: (a) the central processing computer, (b) units for recording and storing information, (c) a transmission control unit regulating communication between student and computer, and (d) the student/author stations. CAI has the capability of providing a high degree of individualized instruction. This two-way interaction between computer and pupil coupled with the timing control features and record-keeping capability make CAI one of the most significant advances in education.

The CAI center located at Florida State University incorporates an IBM 1500 system consisting of an 1800 central processing unit, an 1810 Disk Storage unit, a 1502 Station Control unit, and thirty-two 1510 student/author terminals. This center was established in 1964 and became operational in 1965 using the now outdated 1440 system. The center employs five full-time faculty members, nine technical staff (programmers, coders, and machine operators), six office personnel, and approximately twenty-five graduate student trainees. The purpose of the center is to provide research facilities for various university departments, conduct basic educational research, and train students in theoretical and technical CAI operations and methods of research.

The 1510 student/author terminals in this CAI system utilize unique and sophisticated features to provide maximum interaction between computer and student with minimum requirements of time and effort. Information is presented to the student at the terminal by means of a CRT (cathode-ray tube-television screen) where the student may respond either by typing messages through the electric keyboard or by pressing a "light-pen" against the face of the display screen. Using these two modes of interaction, a highly flexible and efficient process of instruction may be realized.

Origin of the Program

The Naval Training Device Center located at Orlando, Florida, conducts classes for Naval personnel in computer design and maintenance. One of the topics covered in the 28 week Digital Computer Technology course is Boolean algebra, which is the foundation behind computer logic circuits. The Boolean algebra course used a programmed text training manual (NAVSO P-3209) written specifically for Navy servicemen and this course. The military instructors discovered this programmed text to be unsatisfactory since students "completed" the text without attaining the minimal performance skills and concepts required for the Computer Technology course. In 1968, the Navy contracted the FSU CAI Center to revise and enter this Boolean algebra program on its 1440 CAI system with the expectation that higher performance levels would be obtained from this type presentation. In the spring of 1968, this author was assigned to the NTDC Boolean Algebra project with the task of evaluating, revising, supplementing, and making operational a computer presented course in Boolean algebra to be used by the Navy.

Upon examination of the programmed text and after comparisons with numerous Boolean algebra and computer logic textbooks, this author felt it necessary to make several major revisions to the program. This included the addition of a lengthy introduction to the subject, eliminating inadequate exercise problems and inserting better ones, adapting the materials for CAI presentation, and reorganizing and expanding selected concepts. The revised program presented the three Boolean operations and twelve Boolean laws in the context of mathematical logic, the algebra of sets, and electric switching networks. Using these concrete examples the subjects would not be required to memorize abstract mathematical laws, but could rely on intuitive models to derive correct solutions. This revised Boolean algebra program and a 347 page supplementary manual written by this author, was completed for the Navy in December, 1968.

This revised program was also entered on the new 1500 CAI system at FSU as well as the older 1440 system. In the winter of 1968, the material on the 1500 system was used as part of a study to determine the effects on performance of students working under a massed versus distributed practice. Approximately 20 students worked five hours each on the revised materials. This investigation demonstrated that the program could function under realistic operating conditions. After examination of the post-treatment tests, the student questionnaires, and collecting suggestions made by the subjects who participated in the study, numerous corrections and revisions were performed on the program. This experience provided a significant improvement in the clarity and continuity of the instructional materials.

Description of the Program

The revised Boolean Algebra program written by this author is primarily linear in form, following the Skinnerian model, with the capacity to review previous materials whenever necessary. The general content format is to present each new concept in the context of logic, sets, or switches, followed by examples illustrating the concepts, then a series of problem exercises to insure the acquisition of the concept. Periodically review sections are inserted to summarize previously covered materials. The series of problem exercises started with elementary concepts, progressed in difficulty, and reached the most difficult problems at the end of the conceptual sequence. The majority of the questions are multiple-choice type using the light pen, however, keyboard responses are employed whenever necessary or desirable. For incorrect responses, the program automatically transfers the student to various branches which provide the necessary hints related to his particular incorrect answer. Options are also available for "help" or "aid" under the more difficult questions which give step-by-step instructions for obtaining the correct solution to the problem.

The instructional materials were designed so that subjects needed only elementary algebra skills in order to work successfully in the program. Although the materials were relatively simple, the introduction of unfamiliar symbolism, operations, and laws provided content of sufficient difficulty.

Revising Program for Study

In January, 1969, this author decided to adapt the materials from this revised Boolean Algebra program and use them in the present study comparing the achievement of pairs versus individuals. A number of major alterations were necessary in order to conform the program to the experimental objectives and conditions. This altered program to be used in the study was renamed "the PIC program" (Paired Instruction by Computer) to distinguish it from the revised Navy Boolean Algebra program.

The original PIC program consisted of the first five chapters in the introduction to *Boolean Algebra for Digital Computer Circuits*, which included approximately 50 concept units. The external conditions of the experiment demanded that the instruction be restricted to five periods of 50 minutes each. After six pilot subjects completed the program to provide accurate time estimates, the course materials were edited to three chapters of introductory materials and 23 concept units. The final PIC program included these sections:

I. Introduction to Boolean Algebra

II. Three Boolean Algebra
    1. Mathematical logic
    2. Set Theory
    3. Switching Networks

III. Boolean laws similar to laws of ordinary algebra.

The materials were divided into five daily blocks, each block requiring the naïve student approximately 40 minutes to complete. The first block included instructions on operating the equipment and three concept units, thereafter each block consisted of five concept units for a total of 23 units (see Instructional Materials, Chapter 3). Special "preview frames" and "criterion frames" were written for each concept unit which approximate the familiar pretest and post-test questions. These preview and criterion frames were inserted at the beginning and end of each concept unit in the program and a daily quiz was added at the end of each daily block of instruction (See Appendix I for preview, criterion, and quiz questions). Timing considerations produced the greatest difficulty. The program was cut to the very skeletal necessities. All reviews and helps were eliminated; all summaries were removed; more than half of the problem exercises were sacrificed in order to meet the external time requirements. More pilot trials were made to check for technical errors, mathematical inaccuracies, continuity of flow, diagram problems, and total operation of the system. Many editorial hours were spent debugging and correcting the program. Recording devices, switches, and counters were also checked to make certain all data from the experiment would be accurately recorded. Two subjects went through the entire program keeping accurate records of performance to determine any discrepancies in the recording counters and switches in the system. Finally, by April 22, the PIC program was operational.

Examinations for the Program

The PIC program is a sequence of 23 concept units, each concept consisting of (1) a preview question, (2) instruction and problems, (3) a criterion question, (4) a quiz question, and (5) a final examination question. The criterion question appears at the end of each concept unit while the quiz question is located at the end of the daily lesson and the final examination question is given after completing the entire program. As a result, each concept was tested immediately after instruction (criterion), after a short delay (quiz), and after completion of the program (final examination). The materials included 23 preview frames, 23 criterion frames (see Appendix C), 23 daily quiz questions (see Appendix E), and 23 final examination questions (see Appendix E). For each concept, the author attempted to make the preview, criterion, quiz, and final examination questions as nearly identical as possible, so that if the student could successfully work any one of them, he should be able to solve them all. All preview frames, criterion frames, quiz questions, and final examination questions were multiple choice type with exactly four possible answers. The final examination was administered by pencil and paper, while the others were presented by the CRT.

CHAPTER III

EXPERIMENTAL PROCEDURES

Presentation Media

The Boolean algebra instructional materials were presented by means of the IBM 1500 system located at the Florida State University Computer Assisted Instruction Center. Twenty student terminals were available which could accomodate 10 pairs and 10 individuals working simultaneously. Each student terminal consisted of CRT (television screen) presentation output and both keyboard and light-pen response modes as inputs. This CAI system provided a high degree of control in the experiment as well as the capability for recording many performance variables which would be either difficult or impossible using any other presentation media.

Population

Selection of the population for the experiment was based upon the three following criteria.

1. The members in the sample selected from the population must know one another fairly well, that is they must have had previous interaction in order to judge the personality characteristics and intellectual abilities of the other subjects. This is necessary so that students can realistically select suitable partners approximating traditioned groups as desired for the experiment.

2. The population sample must have had little or no previous training in Boolean algebra since the program was designed for this type of subject.
3. The population sample had to be physically present at the Center since terminals could not be remotely located. On-campus populations were most desirable to eliminate transportation and scheduling difficulties.

As a result of these criteria the decision was made to use two mathematics classes, Basic Algebra I, from the University School as the study population. These two classes, both taught by the same teacher, represented a non-accelerated group of 56 students from the ninth through twelfth grades. These subjects met all three criteria. They knew one another very well since most of them had attended the University School since elementary grades and they had been all enrolled in the same Basic Algebra class for eight months prior to the experiment. Hence they were able to judge who would make satisfactory partners. This class was not advanced, hence most members had never been instructed in Boolean algebra although some students were acquainted briefly with intersections and unions of sets and simple Venn diagrams in the eighth grade. Also these subjects were located within easy walking distance since the University School is approximately 4 minutes from the CAI Center.

Table 1 shows some of the population characteristics of these two math classes (ability and achievement characteristics of subjects are listed in Chapter 4).

TABLE 1.--Population characteristics of both mathematics sections

Characteristics	Third Period	Fourth Period
Sex	12 Male	15 Male
	15 Female	14 Female
Grade	8 Ninth	9 Ninth
	12 Tenth	13 Tenth
	7 Eleventh	3 Eleventh
		4 Twelfth
Age	5 Fourteen	6 Fourteen
	12 Fifteen	8 Fifteen
	7 Sixteen	9 Sixteen
	3 Seventeen	4 Seventeen
		2 Eighteen
Total	27 Subjects	29 Subjects

Pair Formation

The objective in the formation of pairs was to create pairs which approximated traditioned groups, as defined by Lorge, since these should benefit most from paired interaction. In order to form traditioned pairs it was felt the subjects should be allowed to select their own partners, choosing their friends or classmates with whom they would like to work in a learning team. The members in each mathematics class were divided into two groups by use of a table of random numbers. Group A consisted of those members who were to work together in pairs while Group B contained those subjects who would work individually. Table 2 shows this breakdown.

TABLE 2.--Number of pairs and individuals per section

Third Period	Fourth Period
Group A - 18 (pairs)	Group A - 20 (pairs)
Group B - 9 (indiv.)	Group B - 9 (indiv.)

Before the experiment began, this author went to the University School and met with the two algebra classes in order to explain the nature of the experiment, give schedule instructions, and get student partner perferences. Each student was given a pair-selection sheet (see Appendix I) showing those class members who were to work in pairs and those who were to work individually. All persons in the paired group were asked to look over the list (of pairs) and select five persons which they would like to have as partners. They were to rank these five selections as first choice, second choice, etc. These pair-selection sheets were then collected by the author. A coordinate system was constructed with each student name appearing along both axes and partner choices were plotted on the grid. The author attempted to form pairs from this matrix so that both members of a pair would be mutual first-choice selections. However, not all pairs were of this type and this method of pairing made it possible that some students were not selected by any member of the class. There were three students in this category, including two boys who had recently moved into town and enrolled in the school. In this case the pairs were formed on the judgment of the teacher. After the final pair formation by the author based on the student preferences, no exchanging of partners was permitted. Table 3 shows the choice ranking of partners, grade, and sex characteristics of the pairs in this study. One pair was split into two individuals when one of the partners was absent the first two days of the experiment, hence only the remaining 18 pairs are shown in Table 3 instead of the original 19. It is interesting to observe in Table 3 that there were no male-female pairs although many pairs were formed with differences in grade, age, and race.

TABLE 3.--Partner choice preferences, grade, and sex characteristics of pairs

Pair	Choices	Grade	Sex
1	1st - 5th	10 - 10	M - M
2	1 - 1	11 - 11	M - M
3	1 - 1	9 - 10	F - F
4	1 - 1	9 - 9	F - F
5	1 - 1	10 - 11	F - F
6	1 - 1	9 - 9	M - M
7	1 - 1	11 - 11	F - F
8	1 - 1	9 - 10	F - F
9	1 - 5	10 - 11	M - M
10	1st - 1st	10 - 11	M - M
11	1 - 3	9 - 9	M - M
12	1 - 1	10 - 10	M - M
13	X - 2	9 - 10	M - M
14	X - X	10 - 10	M - M
15	1 - 1	12 - 12	F - F
16	1 - 1	9 - 12	F - F
17	1 - 3	9 - 9	M - M
18	3 - 5	10 - 10	M - M

(X indicates no selection)

There were no special rules for working together. The paired students were told only that they should work together as a team, discussing problems with each other as often as they felt necessary but they were not permitted to talk with other pairs or individuals. If any disagreements arose between pair members, they should discuss the problem and attempt to reach a mutual decision before answering. If any member of a pair was absent or unable to participate in the instruction, then the other member was not permitted to continue by himself, but was sent to the library.

Schedule of Events

The experiment was conducted over a period of nine days with instruction only on five days. The weekly calendar is shown below:

Friday, April 25 - Introduction to experiment (University School)

Monday, April 28 - Block 1 of instruction (CAI Center)

Tuesday, April 29 - Block 2 of instruction (CAI Center)

Wednesday, April 30 - Block 3 of instruction (CAI Center)

Thursday, May 1 - Make up

Friday, May 2 - Make up

Monday, May 5 - Block 4 of instruction (CAI Center)

Tuesday, May 6 - Block 5 of instruction (CAI Center)

Wednesday, May 7 - Final Examination (University School)

A typical instruction day began when the third period students began to arrive at the CAI Center shortly after 10:00 A.M. They went immediately to their pre-assigned terminals, signed on and started the instructional program. As soon as the lesson was finished for that day, the student was permitted to leave the center and return to school. Although this did cause some confusion it prevented students who had finished from interfering with those still working. The fourth period class repeated the same sequence beginning at 11:10 A.M. Below is the daily schedule of events for both periods:

Third Period Class

10:10 - dismissed from 2nd period, leave for CAI Center
10:15 - arrive CAI Center, begin Boolean program
11:05 - finish daily block, begin Quiz
11:10 - finish Quiz, leave CAI Center
11:15 - arrive at school, begin 4th period

Fourth Period Class

11:10 - dismissed from 3rd period, leave for CAI Center
11:15 - arrive at CAI Center, begin Boolean program
12:05 - finish daily block, begin Quiz
12:10 - finish Quiz, leave CAI Center
12:15 - arrive at school, eat lunch.

The first day of the experiment was used as an introduction and explanation day. The author went to the school and visited both mathematics classes to explain the purposes and procedures of the experiment. The students were given instruction sheets and pair-selection sheets (see Appendix I). The author described the basic content of the program, the structure of the materials with emphasis on function of preview frames and criterion frames, the use of confidence scales, and use of anxiety scales (included for other investigations). Simple instructions were provided on the use of the CAI student terminals with drawings to illustrate the equipment.

Working suggestions and hints were given related to the questions of taking notes and guessing answers; both were discouraged but not prohibited. After explanations and questions the students were allowed to make partner preferences on the sheet given earlier. These sheets were collected by the author and later used to make final pair decisions. The teacher told the classes that their performance on this program would be considered as part of the normal class work and they would receive a grade based upon their final exam and quiz scores. This was done in order to maintain student motivation.

Five full days were devoted to taking the instructional program. Unfortunately, these were not consecutive due to the unscheduled band trip and weekend. However, the delay did not seem to cause any difficulty. Figures 1, 2, 3, 4, 5, and 6 show typical pairs and individuals at work in the program.

ERIC at Stanford is using postcards like this to try to speed-up communication.

EM 007 557

Pages 34-36 deleted due to marginal reproducibility of photographs. Table of contents noted,

The ERIC Clearinghouse on Educational Media and Technology
at the Institute for Communication Research, Stanford, Cal. 94305

The two days (May 1 and May 2) used for make-up work were a result of an unscheduled school band trip which involved one fourth of the subjects. Hence, the decision was made to postpone the experiment these days and resume the following Monday. The make-up days proved to be useful for those students absent during any of the first three instructional days.

Instructional Materials

After all revisions, additions, and deletions the final Boolean algebra program included five daily blocks and twenty-three concept units as shown below:

Block I

(Concept units)

1. Elements in mathematical logic
2. Elements in set theory
3. Elements in switching networks

Block II

(Concept units)

4. AND operation in logic
5. AND operation in set theory
6. AND operation in switching networks
7. OR operation in logic
8. OR operation in set theory

Block III

(Concept units)

9. Special cases in set theory
10. OR operation in switching networks

11. Switching expressions and network diagrams
12. Determining the value of any switching network
13. Special cases in switching networks

Block IV

(Concept units)

14. NOT operation in set theory
15. Finding set corresponding to any expression
17. Equivalence of any two expressions by sets
18. NOT operation in switching networks
20. Determining the value of any expression

Block V

(Concept units)

29. The commutative laws
30. The associative laws
31. The AND distributive law
32. Simplifying expressions with distributive laws
33. Operations with Ø

Each block was designed to be completed within forty minutes. At the end of each block appeared a short daily quiz with one question per concept unit. Paired students used a cooperative effort on these daily quizzes.

This author classified the concept units into two types of learning tasks: memorization tasks and algorithmic tasks. Memorization tasks are questions which require the subject to recall certain information. For example, he may be asked to remember the meaning of symbols, know the definitions of certain terms, or recall forms of

Boolean laws. Algorithmic tasks, on the other hand, are questions which demand some "higher order" thinking as well as remembering. To illustrate, the subject may be required to determine a set in a Venn diagram which corresponds to a complex expression or perhaps he would be asked to derive the Boolean expression which is equivalent to a particular switching network. The algorithmic task involves a well defined procedure or process as well as remembering related facts which the subject must carefully follow in order to determine the correct solution. Once this algorithm has been mastered, he should be able to solve any problem of a similar type.

Table 4 shows the division of concept units into memorization or algorithmic tasks:

TABLE 4.--Division of concept units into memorization and algorithmic tasks

Memorization		Algorithmic	
(Concept Unit	)	(Concept Unit	)
1	10	5	31
2	12	8	32
3	13	11	
4	18	14	
6	29	15	
7	30	17	
9	33	20	
TOTAL	14 Concept Units	TOTAL	9 Concept Units

The Boolean algebra instructional program is not included in the Appendices due to size limitations and since the materials are written in the Coursewriter II programming language. Any interested person desiring to see the entire program should contact Dr. Walter Dick, CAI Center, Florida State University, Tallahassee, Florida 32306.

Instructional Model

The instructional program contains twenty-three concept units. Each concept unit consists of a few introductory statements or examples followed by a chain of questions, beginning with very easy questions, then increasing in difficulty until at the end of the chain is a criterion frame. If the student can correctly answer the criterion frame, he has learned the concept satisfactorily and can proceed to the next concept unit. At the beginning of each concept unit is a preview frame which is only a slight modification of the question in the criterion frame. The purpose of the preview frame is to determine if the subjects knew the concept (or could figure it out) before receiving instruction on that concept. These concept units are arranged in a Gagné-type hierarchial order, with concepts in preceding frames necessary for successful performance in the latter frames. The entire program included 128 question frames excluding the preview, criterion, and quiz problems. Hence there was an average of 5 to 6 problems within each concept unit.

Confidence Scales

A confidence scale was devised in an attempt to measure the "confidence" or "certainty" a subject felt in his response. By examining only the correctness of an answer, the experimenter has no idea whether the student made a lucky guess or whether he knew the solution with absolute certainty. It was hoped that the confidence scale would allow the student to indicate whether he was guessing or whether he was "certain" of his answer. The scale had a five-option range as shown in Table 5.

TABLE 5.--Explanation of confidence scale

Confidence Rating	Meaning
5	worked out the problem - 100% certain
4	eliminated 3 choices - nearly 100% certain
3	eliminated 2 choices - 50 % certain
2	eliminated 1 choice - 33 1/3 % certain
1	guess - uncertain

In an attempt to produce uniformity of the scale usage, the students were given a short instruction with example problems and confidence scales at the beginning of the program prior to Block I. The distinction between a rating of 4 and 5 is rather subtle. A rating of 4 indicates the subject derived his answer by eliminating all other optics although he could not actually "solve" the problem. A rating of 5 means he worked the problem and did not even consider any of the other possible choices.

Confidence scales were included only on preview questions, criterion questions, and all daily quiz questions. The sequence is as follows: prior to a preview frame or criterion frame the message "The following is a preview (confidence) frame. Be prepared to indicate your confidence," would appear on the screen. A multiple-choice question is presented on the screen with four possible choices. The subject selects an answer with his light-pen, then before any feedback the confidence scale is flashed on the bottom of the screen, with the message, "Now indicate your confidence." The subject responds by selecting the number which represents his confidence. After he has indicated his confidence the program provides immediate feedback and either continues to the next frame if he answered correctly or requires him to respond again if he answered incorrectly.

Using a combination of correctness and confidence the author derived a "weighted score" for questions. This "weighted score" ranged from 0 to 9, with the highest score given when the subject was 100 percent certain of his answer and it actually was correct and the lowest score given when he was 100 percent certain of his answer but was wrong. The "weighted score" is not an interval scale but is actually an ordinal scale. The assignment of values from 0 to 9 was arbitrary and for computational simplification. Table 6 shows the weighted scores related to correctness and confidence.

TABLE 6.--Construction of weighted scores

Correct Wrong	Confidence Rating	Weighted Score
C	5	9
C	4	8
C	3	7
C	2	6
C	1	5
W	1	4
W	2	3
W	3	2
W	4	1
W	5	0

The weighted scores were recorded only on preview frames, criterion frames, and daily quiz questions. These scores provided an additional measure of the subjects' knowledge and understanding of a concept.

Difficulties Encountered

The most serious difficulty encountered during the experiment was the inability of slower students to complete the daily lesson and quiz within the specified time limitations. Certain pairs and individuals invariably worked slower than expected and had to continually be enouraged to work faster. A CAI presentation is intrinsically designed so that students may proceed at their own pace, and the imposition of predetermined rates and time limitations diminishes this particular advantage of the individualized instruction. Some students feared they would be late to their next class, hence answered questions quickly and carelessly in order to finish. Students who finished early were allowed to leave, which was another factor which encouraged subjects to answer hurriedly in order to finish so they could also return to school. It was interesting to note that some conscientious fourth-period students remained through part of their lunch period in order to complete the daily lessons.

The second major difficulty was the problem of absenteeism and scheduling make-up sessions. Those who were absent during the first three lessons were able to catch up on Thursday or Friday while the experiment was delayed due to the band trip. Other students who missed work came during their lunch period or after school. The Center bought hamburgers and cokes for those who returned during lunch and provided transportation for those who came after school.

Some difficulties were experienced with the computer and terminal operations. Several times during the instruction, the entire system would suddenly halt so that recording tapes could be replaced or for other mechanical malfunctions. In a few instances a student terminal would not operate properly and a machine operator had to be called to make minor adjustments (such as installing a new light-pen) or if the terminal could not be repaired, the subject had to move to another station.

However, in spite of these difficulties, the CAI system did provide fairly reliable performance and the problems were only minor.

Final Examination

After completing the instructional materials at the CAI Center, each student was given a final examination covering the 23 concept units (see Appendix E). Those students who learned and worked together as pairs were required to perform as individuals on this examination. The test was an attempt to measure how much individual achievement would be obtained from paired learning.

The test questions were multiple choice, similar to criterion and quiz questions, but were on printed pages rather than CRT screen. The examination was administered in the regular classroom during the normal class period. No time restrictions were placed on the subjects; although all students easily completed the examination within the class period. The examination papers were collected and graded by the author. Special care was taken so that personal bias would not be introduced by the grader. Final examination scores were tabulated by each subject and concept unit.

Attitude Questionnaire

In an attempt to obtain a subjective judgment of the Boolean algebra program and an evaluation of the paired learning method, the author created an attitude questionnaire (see Appendix F). Questions were developed from previous paired study questionnaires, a standard CAI attitude question sheet, and the experimenter's own special requirements and interests. The resulting list included 23 items investigating the desirable and undesirable features of CAI, the clarity and effectiveness of the materials in the instructional program, and the difficulties and advantages of learning in pairs. The questionnaire was completed by the subjects after they had finished the final examination.

Data Preparation

Before data analysis could be performed, extensive data preparation and checking had to be completed.

Two subjects were dropped from the study, both individual girls. One girl finished the program but was suspended from school for disciplinary reasons and was unable to take the final exam. The second girl was absent four days during the study and never completed the lessons. As a result of these losses, the study populations consisted of 18 pairs and 18 individuals for a total of 54 subjects.

The CAI system records all student performance on magnetic tape. The data from these tapes had to be removed, printed, edited, checked, and punched on IBM cards before analysis was possible. The records were first printed and edited (deleted records of dropped subjects). The program was designed so that 12 performance variables were recorded in counters. Table 7 shows the contents of these counters.

TABLE 7.--Contents of recording counters

Counter 1	Number of questions answered correctly within concept unit
Counter 2	Total number of questions within concept unit
Counter 3	Percent of questions answered correctly within concept unit
Counter 4	Latency on problem frames in concept unit
Counter 5	Preview frame performance
Counter 6	Preview frame latency*
Counter 7	Preview frame confidence
Counter 8	Criterion frame performance
Counter 9	Criterion frame latency
Counter 10	Criterion frame confidence
Counter 11	Latency on problem frames and instruction frames
Counter 12	Latency on problem frames and criterion frame

* "Latency" defined on page 77.

The program was designed so that data in these counters would be summarized after each concept unit. Although this process was checked and rechecked prior to the experiment, the author felt it necessary to process the total performance records for two subjects by hand in order to be certain all counters were functioning properly. Several programming errors were located and the data was corrected for all subjects. The corrected records were punched on IBM cards, 46 cards per person. Other data not recorded on the system (final exam scores, achievement tests scores, etc.) were punched on cards by a keypunch operator from the Center. All cards were double-checked by the author in an attempt to locate any errors in punching. A few errors were located and these cards were reprocessed. Finally a corrected deck of data cards was obtained and used to analyze the results by means of the CDC 6400 computer located at the Florida State University Computing Center.

CHAPTER IV

RESULTS

Introduction

This chapter includes: the statistical procedures used in this study and their justifications; the reliability estimates for the criterion, daily quiz, and final examination scores; a comparison of the various standardized background measures between the two groups; the examination of the primary question; and finally, an investigation of the evidence related to the fifteen subsidiary questions discussed in the first chapter.

Statistical Procedures

Three basic statistical procedures were used to analyze the data collected during the study. These included a reliability estimate, the F test, and a correlation coefficient.

Reliability Coefficient

Reliability estimates were computed for the criterion frame scores, the daily quiz scores, and final examination scores by means of the Kuder-Richardson internal-consistency Formula Number 20 (Guilford, 1956).

$$r_{tt} = \frac{K}{K-1} \quad \frac{\sigma_t^2 - \Sigma \, PiQi}{\sigma_t^2}$$

where K = number of test items

σ_t^2 = variance of test

Pi = proportion of students responding correctly to item i

Qi = $1 - Pi$

The basic assumptions which must be satisfied in order to justify calculating this statistic are:

1. The test is scored so that correct items are assigned a value of 1 and incorrect items a value of 0, so that the total score is the sum of correct items.
2. The test is measuring a single ability or characteristic of the individual, i.e., it is a unifactor test.

Clearly the first assumption is satisfied by all three tests. The second assumption is not satisfied since these tests examine a variety of abilities. Most educational tests rarely satisfy this assumption since investigators are usually interested in a variety of characteristics. Guilford notes that a multiplicity of characteristics results in a lower correlation between scores on various test items so that the internal reliability estimate is reduced. Therefore, the reliability coefficients obtained in this study are reduced somewhat as a result of the failure to satisfy the second assumption. Table 8 shows the various internal-consistency reliability coefficients calculated for the three tests.

TABLE 8.--Reliability estimates for criterion scores, quiz scores, and final examination scores

Measure	Pairs	Individuals
Criterion Frames	.593	.465
Quiz Questions	.115	.622
Final Examination	.576	.608

Observe in Table 8 that the paired group obtained an unusually low reliability estimate on the daily quiz scores. There are several plausible explanations for this low reliability estimate. One possibility is the time factor. Since the daily quiz appeared at the end of each period, students often rushed to complete the quiz in order to return to school for the next period. This rushing may have caused random-like responses thus lowering the reliability estimate. Another possible explanation is that pair-interactions under examination conditions may have created a conflict situation resulting in random-like behavior. This phenomenon was not directly observable by the author, except when one student privately reported such a conflict.

In spite of these somewhat low internal-consistency reliability estimates, Kelley (1927) states that a reliability estimate of .50 or more is sufficient in order to make decisions related to groups, such as group attitudes or group performances, while reliability coefficients of .94 or better are preferred when making decisions about a specific individual. In view of this, the reliability estimates for the criterion scores and final examination scores appear to be sufficient in order to make decisions about the paired group or the individual group, while conclusions based upon the quiz scores should be approached with caution.

The F Test

The F test is used for most of the comparisons between the paired group and individual group in this study. When only two groups are under consideration the F test is essentially a t test. In order to use this test, three assumptions should be satisfied:

1. Each population under investigation exhibits a normal distribution of scores.
2. The populations under consideration have homogeneous variances, i.e., $\sigma_1^2 = \sigma_2^2$.
3. That error components are statistically independent, i.e., that errors associated with any pair of observations are independent.

Concerning the first assumption, the author believes that the scores from a population of students similar to those in the Basic Algebra I class may not be normally distributed but skewed toward the left. This is suggested since these Basic Algebra students are generally poorer in mathematical ability than those students who take the traditional algebra sequence. The Kolmogorov-Smirnov test was applied to the paired group final examination scores to determine if the sample could have been selected from a normally distributed population. The D value of .038 was not significant at the .10 level indicating that the sample may have been selected from a normally distributed population. In any case, many statisticians indicate a skewed population does not cause serious difficulty, for example, Hays (1965) comments, "inferences made about means that are valid in the case of normal populations are also valid even when the forms of the population distributions depart considerably from normal (p. 378).

To check the second assumption, an F ratio was used to test that $\sigma_P{}^2 = \sigma_I{}^2$. These values were computed on the preview scores and final examination scores for the paired group and individual group. No significant differences were located at the .10 level, therefore the populations satisfy this assumption.

The third assumption that the error components on any measure are statistically independent is accepted as valid for this study. The author, therefore, feels justified in using the F test for comparisons between the groups.

The F test computations were done by means of the Biomedical Computer Program (BMD 01V), Analysis of Variance for One-way Design, version of May 4, 1965, developed by the Health Sciences computing faculty, UCLA. The results of these comparisons are presented later in this chapter.

Correlation Coefficients

Correlation coefficients relating selected performance variables were computed using the Pearson product-moment formula:

$$r_{xy} = \frac{N\Sigma xy - (\Sigma X)(\Sigma Y)}{\sqrt{(N\Sigma X^2 - (\Sigma X)^2)\ (N\Sigma Y^2 - (\Sigma Y)^2)}}$$

where r_{xy} = Pearson correlation

X = score for variable X

Y = score for variable Y

N = number of scores

According to Hays (1965) it is not necessary to make any assumptions about the distribution form, the variability of the scores, or the true level of measurement represented by the scores in order to compute a correlation coefficient for any given set of data. All that is necessary is N distinct cases each having two numerical scores. In order to generalize from the sample data to the population, one must assume the two variables under consideration have a rectilinear relationship. For descriptive purposes of this study, the assumption of a straight-line relationship is acceptable as a first approximation. With this in view, correlation coefficients relating variables were calculated by means of the Biomedical Computer Program (BMD 02D). Results of these computations are presented later in the chapter.

Background Measures

It was assumed that the random distribution of subjects into pairs or individuals would produce groups with equivalent abilities. In order to verify this assumption, the groups were compared using the standardized measures taken from the school records. The following measures were used:

1. Course Grades.--All students who were enrolled in Basic Algebra I received a course grade for the first semester's work. The grades were all given by the same instructor.

For computation purposes, grades were assigned the traditional values of 4 for A, 3 for B, 2 for C, 1 for D and 0 for F.

2. SCAT Scores.--The school records included the verbal and quantitative percentiles on the SCAT (School and College Ability Test). These tests were given to the students when they were in the ninth grade, hence the scores were four years old for some students while only a year old for others. These records were not available for all subjects.

3. Achievement Test Scores.--Also included in the school records were scores on the Florida State-wide Ninth Grade Achievement Tests. The Math I (computation) and Math II (problem solving) scores were collected for this study. Again these records were not available for all subjects.

4. Cooperative Math Test.--All students were given the cooperative Math Test, Algebra I, form A, developed by Educational Testing Service, 1962. The test was administered to the class by the instructor approximately two weeks after the experiment had terminated.

Table 9 shows the means, standard deviatons, and resulting F values comparing the scores of the two groups for these standardized tests and grades.

TABLE 9.--Standardized background measures for pairs and individuals

Measure	Pairs	Individuals	F Ratio
	n = 33	n = 17	
COURSE GRADES	M = 2.18	M = 2.00	F = .41
	sd = .77	sd = 1.22	
	n = 30	n = 13	
SCAT verbal %	M = 58.23	M = 58.92	F = .01
	sd = 24.51	sd = 24.75	
	n = 30	n = 13	
SCAT quantitative %	M = 53.37	M = 59.77	F = .59
	sd = 28.22	sd = 15.30	

TABLE 9--Continued

Measure	Pairs	Individuals	F Ratio
MATH I % computation	n = 28 M = 55.29 sd = 25.62	n = 14 M = 58.00 sd = 23.71	F = .11
MATH II % problem solving	n = 28 M = 55.11 sd = 23.14	n = 14 M = 58.79 sd = 16.25	F = .28
Algebra I % Coop. Math Test	n = 33 M = 50.55 sd = 23.00	n = 17 M = 43.06 sd = 26.16	F = 1.08

None of the comparisons presented in Table 9 was significant at the .05 level. The variations in the sample sizes within the different comparisons were a result of incomplete records. The actual sizes were n = 36 (18 pairs) and n = 18 for the individuals. In view of this, the SCAT and Achievement Test comparisons may have little significance, but were presented for what they may be worth. As a result of these comparisons, the author concluded there were no differences between the two groups with respect to mathematical ability or achievement.

Primary Question

The primary question under investigation in this study was the relative achievement of those students who learn in pairs with those who learn independently when all subjects are examined individually.

In order to determine the relative achievement, the mean paired final exam score was compared with the mean individual final exam score using the one-way analysis of variance program.

The null hypothesis was:

H_o: There are no significant differences between the mean final exam score for the paired group and the mean final exam score for the individual group.

The alternate hypothesis was:

H_1: The mean scores between the two groups are not equal.

Table 10 presents the final examination mean scores and standard deviations for the two groups. The maximum score was 23 so that the individuals averaged 54 percent while the pairs averaged 51 percent.

TABLE 10.--Mean scores and standard deviations on final examination

Group	Subjects	Mean	Std. Dev.
Pairs	36	11.67	3.22
Individuals	18	12.56	3.40

A critical value of $\alpha = .05$ was selected and the corresponding **F** value was $F_{(1,50)} = 4.02$. When comparing the mean final examination scores for the two groups the calculated value was $F = .883$, hence the null hypothesis could not be rejected.

Table 11 shows the frequency distribution of final examination scores for the groups.

TABLE 11.--Frequency distribution of final examination scores for pairs and individuals

Number Correct	Pairs	Individuals
23	0	0
22	0	1
21	0	0
20	1	0
19	0	0
18	1	0
17	1	0
16	0	2
15	3	0
14	3	3
13	6	1
12	4	5
11	3	3
10	4	1
9	3	0
8	4	0
7	2	2
6	1	0
5	0	0
	36	18

Table 12 presents the frequency of correct responses across the 23 concept units. For example, on question two, 27 of 36 answer correctly in the paired group (75%) while 17 of 18 individuals were correct.

TABLE 12.--Final examination scores across concept units for pairs and individuals

Concept Unit	No. Pairs Correct (N = 36)	No. Indiv. Correct (N = 18)	Percentage Pairs Correct	Percentage Individuals Correct
1	22	10	61	56
2	27	17	75	95
3	25	14	69	78
4	24	11	67	61
5	21	12	58	67
6	6	7	17	39
7	24	11	67	61
8	14	11	39	61
9	17	5	47	28
10	34	17	92	95
11	17	10	47	56
12	25	12	69	67
13	8	6	22	33
14	11	9	31	50
15	17	9	47	50
17	4	4	11	22
18	8	3	22	17
20	25	11	69	61
29	27	12	75	67
30	18	9	50	50
31	8	7	22	39
32	21	9	58	50
33	17	9	47	50

Although the two groups had equivalent total scores, Table 12 suggests a comparison between scores (frequencies) within each concept unit to determine the agreement over individual questions. In order to determine the agreement between the two groups, a correlation coefficient was computed. The resulting value was r = .588 which is significant at the .001 level. Hence the pairs and individuals performed similarly across the concept units.

Therefore, concerning the primary question under examination in this study, there are no significant differences between final achievement when students learn together in pairs and when they learn individually using the computer assisted instruction system.

Subsidiary Questions

Question 2

Does this Boolean Algebra program teach the subjects, that is, is there any increase in achievement as a result of participating in the study?

In an attempt to determine if the subjects learned any Boolean algebra, comparisons were made between the entering performance and exiting performance. The preview frame scores are an estimation of entering ability since each preview frame appears before the introduction of a particular concept. The criterion frame scores, the daily quiz scores, and the final examination scores each represent various stages of their exiting abilities. If the subjects do actually learn as a result of the instructional materials, then one would obviously expect a significant increment from the preview scores to the other testing periods.

The null hypothesis used for these comparisons was:

H_o: For each group, there is no difference between the mean preview frame scores and the mean exit scores (criterion, quiz, and final).

Again, the statistical method for the comparison was a one-way analysis of variance and $\alpha = .05$. Table 13 shows the mean scores and standard deviations for the entry test (preview) and the exit tests (criterion, quiz, and final examination).

TABLE 13.--Mean performance scores on preview, criterion, daily quiz, and final examination questions

Measure	Pairs	Individuals
Preview (entry)	n=18 M=9.06 sd=2.96	n=18 M=8.67 sd=1.75
Criterion (exit concept)	n=18 M=12.06 sd=2.96	n=18 M=11.28 sd=2.80
Daily Quiz (exit block)	n=18 M=8.44 sd=2.20	n=18 M=8.28 sd=3.21
Final Exam (exit course)	n=36 M=11.67 sd=3.22	n=18 M=12.56 sd=3.40

Table 14 presents the computed F values for the various comparisons.

TABLE 14.--Entry vs. exit differences for pairs and individuals

Comparisons	Pairs	Individuals
Preview vs. Criterion	F=11.68	F=6.33
Preview vs. Quiz	F=.67	F=.12
Preview vs. Final Examination	F=9.48	F=11.28

Comparing the preview frame scores and the criterion frame scores, the critical value if $F_{(1,34)} = 4.13$ for $\alpha = .05$, thus for both the pairs and the individuals the null hypothesis must be rejected and there is a significant increase in scores from the preview frames to the criterion frames.

Comparing the preview frame scores and the daily quiz scores, the critical value is again $F_{(1,34)} = 4.13$ so the null hypothesis is not rejected. Therefore, this data shows no significant difference between the preview and quiz scores for both the pairs and individuals.

Comparing the preview and final examination scores, the critical value is $F_{(1,52)} = 4.03$ for $\alpha = .05$, thus for both the pairs and individuals the null hypothesis is again rejected and there is a significant increase from the preview scores to the final examination scores.

As a matter of interest, for both the pairs and individuals there was a significant decrease from criterion scores to quiz scores, a significant increase from quiz scores to final examination scores, but no differences between criterion scores and final examination scores.

In an attempt to explain the decrease in daily quiz scores, an item analysis was made over all the questions and concept units. This analysis is presented in Appendix F and is discussed in detail in Chapter V.

Table 15 presents a preview, criterion, daily quiz, and final examination profile across the 23 concepts for the paired group. Each score represents the number of subjects answering the preview, criterion, quiz, and final question correctly for a given concept unit. For example, on the third concept unit, one pair answered the preview frame correctly, three pairs answered the criterion correctly, nine pairs answered the quiz, and 25 members of the paired group (working individually) answered correctly on the final examination. The horizontal lines divide the concept units into the five lesson blocks.

TABLE 15.--Preview, criterion, daily quiz, and final examination profile across concept units for paired group

Concept Unit	Preview (N=18)	Criterion (N=18)	Quiz (N=18)	Final (N=36
1	2	11	1	22
2	14	11	5	27
3	1	3	9	25
4	17	17	9	24
5	6	18	12	21
6	13	11	8	6
7	13	14	10	24
8	9	1	13	14
9	5	3	6	17
10	16	16	15	34
11	4	12	5	17
12	15	17	5	25
13	4	4	5	8
14	4	11	5	11
15	3	11	2	17
17	1	8	5	4
18	8	4	1	8
20	12	13	11	25
29	2	14	2	27
30	7	1	5	18
31	3	6	2	8
32	2	5	6	21
33	2	6	10	17

Table 16 shows the preview, criterion, daily quiz, and final examination profile across the concept units for the individual group.

TABLE 16.--Preview, criterion, daily quiz, and final examination profile across concept units for indidivual group

Concept Unit	Preview (N=18)	Criterion (N=18)	Quiz (N=18)	Final (N=18)
1	4	7	4	10
2	13	13	6	17
3	2	3	11	14
4	16	15	8	11
5	12	16	5	12
6	12	15	9	7
7	7	6	5	11
8	13	1	15	11
9	0	5	2	5
10	14	15	17	17
11	4	13	9	10
12	14	15	5	12
13	1	5	6	6
14	4	6	5	9
15	3	11	3	9
17	8	8	4	4
18	6	7	4	3
20	12	9	12	11
29	5	11	4	12
30	1	3	5	9
31	3	8	1	7
32	1	6	5	9
33	1	5	4	9

Although there was a significant increase from the preview scores to the criterion and final examination scores, examination of Table 15 and Table 16 shows that such increases were not uniform, with preview scores exceeding or equalling both the criterion and final examination scores in six cases for pairs and four cases for individuals. In general though, the results indicate that both the paired group and the individual group learned some Boolean algebra as a result of participating in the program.

Question 3

How do pairs and individuals compare in achievement during the instructional phase of the program?

In an attempt to understand how partners work together during the learning process, the paired group and individual group performance was compared on the materials during the instructional phase of the program. The "instructional phase" of the program is defined as all the explanations, examples, questions, and criterion frames, excluding the preview frames and daily quizzes. Two measures were selected as indicators of achievement during this phase. These were the total number of questions answered correctly within the concept units (128 total) and the scores on the criterion frames. The criterion frames were considered as part of the instructional phase of the program since there was a high degree of continuity between the materials in the program and the criterion frames.

The two null hypotheses used to investigate this question were:

H_o: There is no significant difference between the mean number of correct questions for pairs and individuals.

H_o: There is no significant difference between the mean criterion scores for pairs and individuals.

Again, the one-way analysis of variance was used to compute the F ratio and $\alpha = .05$. Table 17 shows the results of these comparisons.

TABLE 17.--Instructional phase performance for pairs and individuals

Measure	Pairs	Individuals	F Ratio
Number of Correct Questions	n = 18 M = 83.56 sd = 12.33	n = 18 M = 82.22 sd = 11.12	F = .12
Criterion Score	n = 18 M = 12.06 sd = 2.96	n = 18 M = 11.28 sd = 2.80	F = .66

Table 18 presents the frequency distributions for the pairs and individuals on the criterion scores.

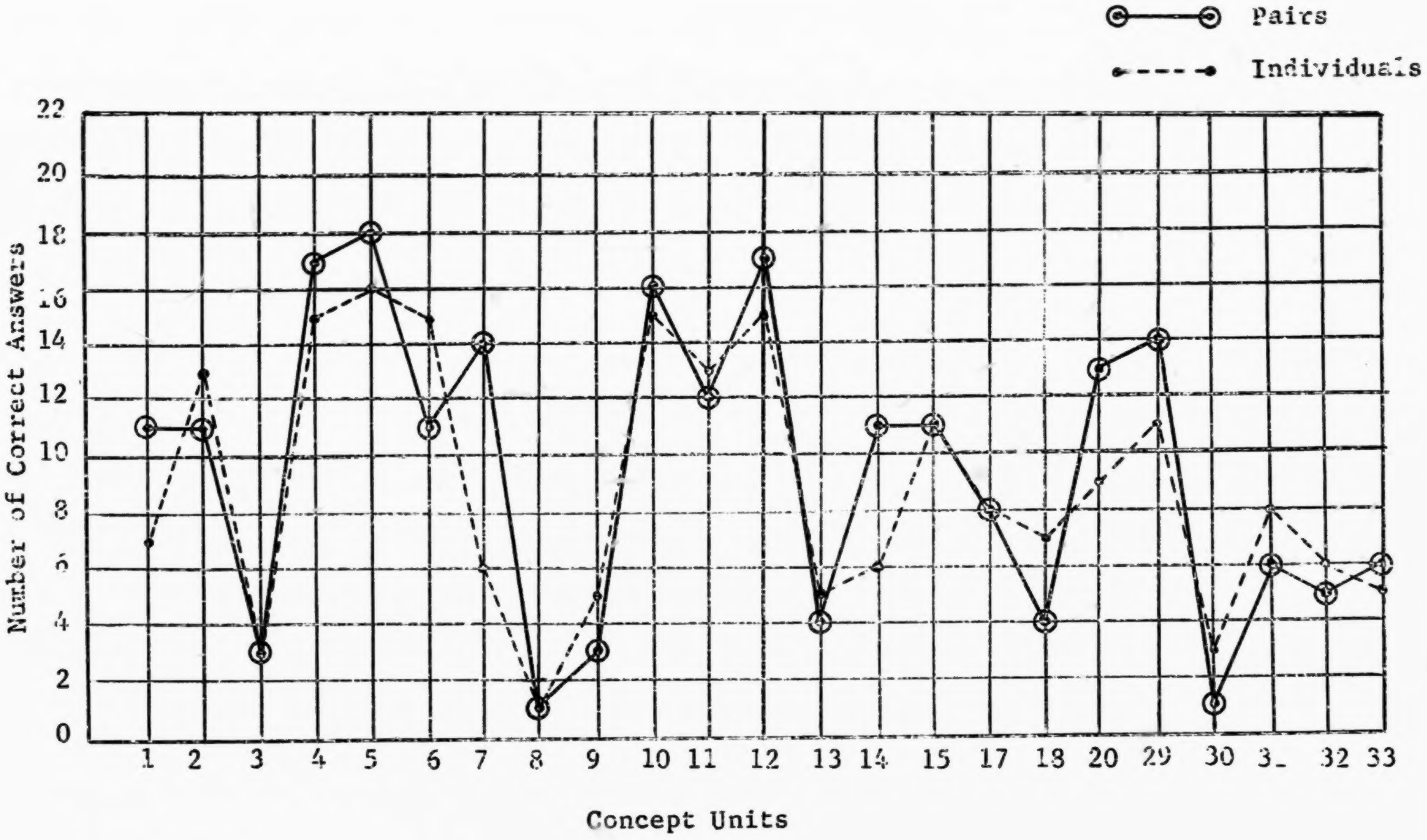
TABLE 18.--Frequency distribution of criterion scores for pairs and individuals

Criterion Frame Score	Pairs	Individuals
20	0	0
19	0	0
18	0	1
17	1	0
16	0	2
15	2	0
14	4	2
13	2	3
12	3	0
11	1	3
10	1	0
9	2	3
8	1	4
7	0	0
6	0	0
5	1	0
4	0	0
	N=18	N=18

The critical value was $F_{(1,34)} = 4.13$ for $\alpha = .05$ hence the null hypotheses were not rejected for either case. From this, one concludes that the pairs and individuals had approximately equivalent performances during the learning phase of the program.

Table 19 presents the criterion frame profile across all concepts for both groups. One can easily see the similarity in the profiles indicating that the pairs and individuals performed equivalently within the learning phase.

TABLE 19.--Criterion frame profile for pairs and individuals



Question 4

How does achievement during the learning phase correlate with achievement during the examination phase?

In order to examine this question, there was an attempt to find how the number of correct questions and criterion scores related to the daily quiz scores and the final examination scores.

Pearson product-moment correlation coefficients were computed between these performance variables by means of the Biomedical Computer Program (BMD 02D). These estimations were derived from the individual total scores (as opposed to individual concept scores) to produce the correlation coefficients shown in Table 20.

TABLE 20.--Correlation between instructional phase scores and examination scores

Measures	Pairs		Individuals	
	Quiz Score	Final Exam	Quiz Score	Final Exam
Number correct problems	.70**	(F_1) .80** (F_2) .50*	.58*	.75**
Criterion score	.58*	(F_1) .80** (F_2) .33	.29	.29

** significant at .01 level
* significant at .05 level

For 16 degrees of freedom, a correlation of $r = .4683$ is significant at the .05 level, while $r = .5897$ is significant at the .01 level. Clearly the number of correct problems correlated significantly with the quiz and final examination scores for both the pairs and individuals, while the criterion scores appear to correlate significantly for the pairs but not for the individuals. Table 20 includes two entries, F_1 and F_2, because paired members worked together on the criterion frames and problems but worked independently on the final examination. Since correlations may only be computed for equal sets of scores, the final examination scores had to be correlated separately. Each pair was alphabetically arranged into a first member, F_1, and a second member, F_2.

Table 20 shows the correlations between these variables based on calculations from the mean scores. Correlations were also computed between these same variables, but in this case each concept unit was considered as an independent observation. Table 21 shows the results.

TABLE 21.--Criterion scores correlated with daily quiz and final examination scores when each concept unit is considered as an independent observation

	Pairs		Individuals	
	Daily Quiz	Final Exam	Daily Quiz	Final Exam
Criterion Scores	-.13	(F_1) -.12 (F_2) -.17	-.06	-.10

Although the mean criterion scores correlated significantly with the mean final examination scores for the paired group in Table 20, the same correlations were not significant when each concept unit was considered as an independent observation in Table 21.

Question 5

How do pairs working together on an examination compare with students working individually?

Are two heads better than one in an examination situation? The five daily quizzes were included in the study to investigate this question. On all daily quizzes, the partners were allowed to work together, pooling their knowledge and memory on the questions. The quiz scores were usually poor for both groups, being approximately equivalent to the preview scores. One should also keep in mind the low reliability estimates for the daily quiz scores presented in Table 8. In any case, comparisons were made between the two groups using the null hypothesis that there were no significant differences. Table 22 shows the results of this analysis.

TABLE 22.--Comparisons of daily quiz scores for pairs and individuals

Measure	Pairs	Individuals	F Ratio
Quiz Scores	n = 18 M = 8.44 sd = 2.20	n = 18 M = 8.29 sd = 3.21	F = .03

Although the pairs did score slightly higher on the quizzes than the individuals, the difference was not statistically significant at the .05 level and the null hypothesis was not rejected.

Table 23 shows the frequency distribution of the daily quiz scores for the pairs and individuals.

TABLE 23.--Frequency distribution of daily quiz scores for pairs and individuals

Quiz Score (23 max)	Pairs	Individuals
15	0	1
14	0	1
13	1	2
12	1	1
11	0	0
10	2	0
9	6	4
8	3	2
7	2	2
6	1	2
5	1	1
4	1	1
3	0	0
2	0	1
	N=18	N=18

Table 24 shows the daily quiz profile across the 23 concept units for both groups.

TABLE 24.--Daily quiz profile across concept units for pairs and individuals

Concept Unit	Pairs (N=18)	Individuals (N=18)
1	1	4
2	5	6
3	9	11
4	9	8
5	12	5
6	8	9
7	10	5
8	13	15
9	6	2
10	15	17
11	5	9
12	5	5
13	5	6
14	5	5
15	2	3
17	5	4
18	1	4
20	11	12
29	2	4
30	5	5
31	2	1
32	6	5
33	10	4

Question 6

What is the relationship between the achievement of paired members when they are required to perform independently?

Since paired members worked and learned together, one would predict that their individual final examination scores should be nearly equivalent. If one member of the pair obtains a low score, the other partner would also be expected to have a low score. Table 25 presents the two final examination scores, F_1 and F_2, for the two paired subjects.

TABLE 25.--Pair scores on final examination

Pair	F_1	F_2
1	9	13
2	6	10
3	8	18
4	8	14
5	9	14
6	11	13
7	12	10
8	7	15
9	12	20
10	12	13
11	15	17
12	7	11
13	10	13
14	8	8
15	14	13
16	15	12
17	9	10
18	13	11

A correlation coefficient was computed between the pairs of scores presented in Table 25. The resulting value was $r = .197$, which is not significant at the .05 level.

The scores in Table 25 showed that in most cases, one member scored higher than his partner. Did some members make significantly better scores than their respective partners? This question was examined by performing a _t_ test on the difference $F_2 - F_1$ for each pair. The resulting value was $t = 3.169$ which is significant at the .01 level. Thus the differences between two partner scores are significant.

Another approach is to examine the agreement between partners on each of the 23 concepts rather than on the total scores. For any given question there are three possible ways the partners may answer: both answer correctly, both answer incorrectly, or one correctly and the other incorrectly. The partners were defined to be in "agreement" if they both answered correctly or both answered incorrectly for a given concept. They are defined to be in "disagreement" if one answers correctly and the other answers incorrectly. Table 26 shows the agreement and disagreement for all the pairs on the 23 final examination questions. For example, the first pair answered 13 questions identically and 10 questions differently for a total of 23 questions.

TABLE 26.--Agreement and disagreement between partners on final examination questions

Pair	Number of Questions in Agreement	Number of Questions in Disagreement
1	13	10
2	15	8
3	13	10
4	11	12
5	12	11
6	13	10
7	15	8
8	15	8
9	15	8
10	14	9
11	13	10
12	11	12
13	12	11
14	13	10
15	12	11
16	18	5
17	12	11
18	15	8

For all the pairs, the mean number of questions answered in agreement was 13.5, that is, in 59 percent of the test the partners answered identically while in 41 percent of the questions they responded differently.

A more detailed examination of the relationship between the partner scores was obtained by considering each concept as independent observation. Each of the 23 concepts had 18 pairs of scores for a total of 414 pairs of scores (23 X 18 = 414). A Pearson correlation was computed to determine the relative agreement between these observations. The resulting value was r = .21 which again was not significant at the .05 level. Thus the partners answered the final examination questions relatively independent of each other, with very little agreement, and with one member scoring significantly higher than the other.

Question 7

How do pairs and individuals compare in the various time measures?

Although final achievement is of major importance in instruction, time factors must also be taken into consideration in order to obtain maximum instructional efficiency. Instructional time factors become increasingly important when considering the operational costs for CAI equipment and personnel. Four time measures were recorded for the subjects in an attempt to investigate this question: (1) total program time, (2) instructional time, (3) problem time, and (4) the latency times.

The "total program time" is the number of minutes elapsed from the initial "sign on" until the final "sign off." This is the cumulative time the subject sits at the terminal and does not include time spent on the final examination. The "instructional time" includes the number of minutes the subject spends on the explanation frames, the example frames and the question frames in each concept unit, exclusive of the preview and criterion frames. The "problem time" is the number of minutes required for each subject to answer questions and problems in the program. This includes the criterion frames since they are problem frames built into the instruction. There are three "latency" times. A "latency" is the time lapse from when the question first appears on the screen until the time when the subject makes his initial response. A distinction should be made between first-pass latency and total latency. First-pass latency is the time until the subject _first_ responds, while total latency is the time required for the subject to answer the problem _correctly_ (which may require several responses). The four latency times recorded were the first-pass preview, criterion, and quiz latencies and the total criterion latency.

It was anticipated that the pairs would probably require more time than individuals as a result of the discussion and interaction. The null hypothesis for making the time comparisons was:

> H_o: There are no significant differences between the pair times and individual times for any of the time variables recorded.

Comparisons were made by the one-way analysis of variance method and again $\alpha = .05$. Table 27 presents the results of these calculations.

TABLE 27.--Time measures and comparisons between pairs and individuals

Measure	Pairs	Individuals	F Ratio
Total Program Time	n = 18 M = 236.0 min sd = 44.34	n = 18 M = 238.56 min sd = 52.94	F = .03
Instructional Time	n = 18 M = 95.8 min sd = 29.24	n = 18 M = 104.3 min sd = 28.83	F = .76
Problem Time	n = 18 M = 58.9 min sd = 16.00	n = 18 M = 61.6 min sd = 21.22	F = .18
Preview Latency	n = 18 M = 14.1 min sd = 4.89	n = 18 M = 15.1 min sd = 5.57	F = .31
Criterion Latency	n = 18 M = 12.2 min sd = 5.12	n = 18 M = 12.7 min sd = 7.93	F = .04
Total Criterion Latency	n = 18 M = 14.6 min sd = 5.32	n = 18 M = 16.3 min sd = 9.32	F = .46
Quiz Latency	n = 18 M = 12.4 min sd = 4.81	n = 18 M = 11.4 min sd = 7.08	F = .21

Examination of Table 27 shows that none of the differences was significant at the .05 level. It is interesting to observe that although there were no significant differences, the paired subjects required less time in every case except for the daily quizzes. This will be discussed in Chapter 5.

Table 28 shows some typical time estimates required for various parts of the program.

TABLE 28.--Typical time estimates

Total Instructional Time	236	minutes
Daily Instructional Time	47	minutes
Single Preview Latency	38	seconds
Problem Time Per Concept Unit	2.6	minutes
Instruction Time Per Concept	4.4	minutes
Criterion Latency	33	seconds
Total Criterion Latency	40	seconds
Quiz Latency Per Question	30	seconds

In order to thoroughly investigate the time variable, one must examine the relationship between the time factors and the achievement. Do subjects who complete the program quickly have high scores or low scores? Does a long latency time indicate the subject will probably answer the question incorrectly? A number of correlation coefficients were computed between the time measures and achievement scores. Table 29 shows correlations between latency and scores for the preview, criterion, and daily quiz scores.

TABLE 29.--Correlations between latencies and scores

Comparison	Pairs	Individuals
Preview latency vs. Preview scores	r = .23	r = .53**
Criterion latency vs. Criterion scores	r = .68**	r = .34
Quiz latency vs. Quiz scores	r = .37	r = .52**

** significant at .01 level
* significant at .05 level

The latency and scores in Table 29 correlated significantly at the .05 level for the pairs on the criterion frames only, while they were significant for the individuals on the preview and quiz frames but not on the criterion. All correlations were positive indicating the longer the latency the higher the scores.

Table 30 shows a correlation matrix between the time variables and the examination scores. Calculations were made between mean times and mean scores rather than considering each concept unit as an independent measure.

TABLE 30.--Correlation matrix-time variables vs. performance variables

	Pairs				Individuals		
	Criterion Score	Quiz Score	Final (F_1)	Final (F_2)	Criterion Score	Quiz Score	Final
Program Time	.65**	.60**	.61**	.59**	.16	.44	.46
Instructional Time	.59**	.62**	.61**	.51**	.07	.53**	.56**
Problem Time	.63**	.62**	.72**	.57**	.21	.59**	.55**
Total Criterion Latency	.64**	.62**	.67**	.64**	.24	.69**	.65**

** significant at .01 level
* significant at .05 level

Examination of Table 30 reveals that time factors and achievement are significantly related for the pairs (.01 level) and also for the individuals with the complete exception of the criterion scores. None of the time factors correlated significantly with the criterion scores for the individuals while all of them did for pairs.

Question 8

Do pairs make fewer errors when answering questions than individuals?

Error rates were investigated as a result of the claims in the literature that pairs make fewer errors than individuals since they are able to discuss questions and check each other.

In this study, an error is counted each time the respondent selects an incorrect response on a multiple choice question. The number of errors does not necessarily reflect the number of incorrect responses since it is possible for two subjects to both miss a question such that one had only a single error while the other made three or four errors. Errors were recorded only on the criterion frames (hence for 23 frames per subject). The mean number of errors of the paired group was compared with the mean number of errors for the individual group using the null hypothesis that there were no significant difference between the means. Table 31 shows the means, standard deviations and F ratio for number of errors over all 23 criterion frames.

TABLE 31.--Number of errors on criterion frames

Measure	Pairs	Individuals	F Ratio
Number of Errors on 23 Criterion Frames	n = 18 M = 22.1 sd = 6.85	n = 18 M = 25.1 sd = 7.58	F = 1.50

Although the pairs did make fewer errors than the students working separately, the difference was not significant at the .05 level and the null hypothesis was not rejected.

The number of errors is often related both to time factors and achievement measures in a learning situation. Table 32 shows the correlation coefficients between the number of errors on the criterion frames and examination scores and time measures.

TABLE 32.--Correlation coefficients of number of errors versus performance variables

Number of Errors Versus	Pairs	Individuals
Criterion Scores	-.92**	-.83**
Daily Quiz Scores	-.52*	-.34
Final Exam Scores	-.18 (F_1) -.66*(F_2)	-.45
Program Time	-.52*	-.26
Instructional Time	-.49*	-.31
Problem Time	-.52*	-.37

** significant at .01 level
* significant at .05 level

Examination of Table 32 reveals that the number of errors correlates significantly with the test scores and the time measures for the paired group, but they correlate only significantly with the criterion scores for the individuals. Negative correlations indicate fewer errors are associated with lower scores and shorter time. Thus for the pairs, those who make fewer errors also require less time during the instruction.

Question 9

How do pairs and individuals compare in the confidence of their answers?

Confidence is a subjective measure of the "certainty" of a student's response to a question. It was conjectured that as a result of interaction, the pairs would discuss problems and indicate a higher confidence than individuals. Previous studies have indicated a high correlation between confidence and achievement. Confidence ratings were recorded on preview frames, criterion frames, and quiz problems. Comparisons were made between pairs and individuals on all three levels using the one-way analysis of variance. The null hypothesis was that there were no differences between pairs and individuals in any of these confidence measures. Table 33 shows the results of comparisons between confidences.

TABLE 33.--Comparisons of confidence measures between pairs and individuals

Confidence Measure	Pairs	Individuals	F Ratio
Preview Confidence	n = 18 M = 73.8 sd = 16.3	n = 18 M = 63.1 sd = 13.9	F = 4.57
Criterion Confidence	n = 18 M = 84.4 sd = 17.6	n = 18 M = 77.6 sd = 12.7	F = 1.76
Daily Quiz Confidence	n = 18 M = 84.4 sd = 14.5	n = 18 M = 73.8 sd = 13.6	F = 5.20

The critical value at the .05 level is F = 4.17, hence the null hypothesis is rejected for both the preview confidences and the quiz confidences but not the criterion confidences, however $p > .75$ in this case. The average confidence rating per concept for pairs was 3.51 of a possible 5, while for individuals it was 3.10. From these measures it appears that pairs are in fact more confident that those who must work alone.

Question 10

How are confidence measures related to other performance variables?

Although pairs indicate more confidence in their responses than individuals, this difference is unimportant unless confidence is related in some manner to achievement. Do students who indicate they are "certain" of their score actually make higher scores? Table 34 presents the product-moment correlations relating confidence and performance for pairs and individuals.

TABLE 34.--Correlation coefficients between confidence ratings and scores on the preview, criterion, and quiz questions

Comparison	Pairs	Individuals
Preview Confidence vs. Preview Score	.32	.41
Criterion Confidence vs. Criterion Score	.55*	.06
Quiz Confidence vs. Quiz Scores	.08	.26

** significant at .01 level
* significant at .05 level

The pairs had the only significant correlation (at .05 level) which was between the criterion confidence and the criterion score. These findings contradict those reported in Chapter I by Massengill and Shuford (1967), hence in this study confidence ratings appear to be actually independent of achievement.

Actually, the confidence scales were introduced in this study as an attempt to derive a more accurate measure of the student's true understanding of a particular concept. Combining the confidence ratings and the correctness for a question, the author derived a "weighted score" as described in Chapter III. Hence each subject also obtained a weighted preview score, a weighted criterion score, and a weighted quiz score. Table 35 shows the comparisons between pairs and individuals on these weighted scores.

TABLE 35.--Comparisons of weighted scores

Weighted Score	Pairs	Individuals	F Ratio
Weighted Preview	n = 18 M = 102.6 sd = 15.9	n = 18 M = 101.5 sd = 12.1	F = .06
Weighted Criterion	n = 18 M = 118.0 sd = 16.6	n = 18 M = 110.4 sd = 20.4	F = 1.49
Weighted Quiz	n = 18 M = 89.2 sd = 18.7	n = 18 M = 91.6 sd = 20.0	F = .14

Examination of Table 35 demonstrates there were no significant differences between the groups on any of the weighted scores.

Correlations were determined between actual scores and the weighted scores for the preview, criterion, and quiz frames. All three correlations were significant at the .001 level for the paired group scores (.72, .89, and .95) but for the individuals only the preview and quiz correlations were significant at .001 level (.76 and .90) while the criterion and weighted criterion were not significantly related.

Question 11

Is there any experimental evidence which supports the claim that paired interaction consists of pooled information or knowledge?

Very little is definitely known about the nature of paired interaction when students are engaged in the learning process. Hudgins (1960) and Maurer (1968) [illegible] interaction is nothing more than a pooling of background knowledge which each member brings to the team and shares with his partner. The author investigated the nature of "pooling" by comparing the preview frame scores of the pairs and individuals. Since the preview frames are encountered at the beginning of each unit, then they provide a measure of what the subjects knew or could guess about a particular concept prior to receiving instruction. The preview frame scores should provide an estimate of the background knowledge. One would expect that if pooling were actually taking place the pairs should score higher on the preview frames as a result of combining their previous knowledge. The null hypothesis was that there were no significant differences between the paired group and the individuals in their preview scores. Table 36 presents the results of the comparison.

TABLE 36.--Comparison of preview scores as an indication of the pooling effect

Comparison	Pairs	Individuals	F Ratio
Preview Scores	n = 18 M = 9.06 sd = 2.26	n = 18 M = 8.67 sd = 1.75	F = .33

Although the pairs did score higher than the individuals on the preview frames, the difference was not significant at the .05 level and the null hypothesis was not rejected. Therefore, no pooling effects were detected by comparing the mean preview scores. Tables 37 and 38 show the two groups had similar performance on the individual concepts as well as the mean scores.

Table 37 is a frequency distribution for the preview frames.

TABLE 37.--Frequency distribution of preview scores for pairs and individuals

Preview Score (23 max)	Pairs	Individuals
16	0	1
15	0	1
14	0	0
13	2	0
12	0	0
11	2	3
10	3	2
9	5	0
8	2	5
7	2	3
6	1	0
5	0	1
4	1	0
3	0	2
	18	18

Table 38 compares the preview scores across concept units for pairs and individuals. As before, these profiles demonstrate there is a relatively high degree of agreement on the preview scores across the concept units.

TABLE 38.--Preview scores across concept units for pairs and individuals

Concept Unit	Number Pairs Correct (N=18)	Number Individuals Correct (N=18)
1	2	4
2	14	13
3	1	2
4	17	16
5	6	12
6	13	12
7	13	7
8	9	13
9	5	0
10	16	14
11	4	4
12	15	14
13	4	1
14	4	4
15	3	3
17	1	8
18	8	6
20	12	12
29	2	5
30	7	1
31	3	3
32	2	1
33	2	1

Question 12

Is there any experimental evidence which supports the claim that paired interaction consists of a generation of new knowledge not possessed by either pair member prior to the interaction?

Another claim about the nature of paired interaction during the learning was that pairs are able to generate new ideas, insights, and knowledge as a result of discussing and thinking together (Tuckman, & Lorge, 1962; Hall, Mouton, & Blake, 1963). In an attempt to investigate this claim, the author compared the "differential" scores between the pairs and individuals. Two types of differential scores were compared: criterion-differential scores and final-differential scores. A "criterion-differential" score is defined as a case when the preview frame was answered incorrectly while the criterion frame was answered correctly within a given concept unit. A "final-differential" score is defined as a case when the preview was answered incorrectly but the corresponding final examination question was answered correctly. An incorrect preview frame indicated that neither member of the team "knew" the answer prior to the instruction for that particular concept. A correct response on the criterion frame indicated that at least one member "learned" from the instruction. If pairs actually do generate new knowledge or insights as a result of interaction, they should have higher differential scores. Table 39 presents the results from comparing the pairs and individuals on their criterion-differential scores and final-differential scores.

TABLE 39.--Comparisons between criterion and final differential scores

Comparison	Pairs	Individuals	F Ratio
Preview-Criterion Differential	n = 18 M = 6.11 sd = 1.94	n = 18 M = 5.50 sd = 1.98	F = .88
Preview-Final Differential	n = 36 M = 6.64 sd = 2.06	n = 18 M = 7.17 sd = 2.60	F = .66

Although the pairs obtained a higher criterion-differential score, they had a lower final-differential score. In either case, however, the differences were not significant at the .05 level, indicating that in this study, the pairs did not "generate" more knowledge or insights than the individuals.

Question 13

Assuming that certain selected pairs may be described as "successful pairs," how do these pairs compare with the individuals on the performance variables?

Certain pairs appeared to work together harmoniously while other pairs developed obvious personality conflicts. Hostility and disagreement would certainly influence performance of the pair during the program. As a result the author attempted to identify those "ideal" pairs and eliminate those pairs where one or both members appeared to be unhappy or dissatisfied when working in a paired situation.

Three criteria were used to define a "successful pair." Pairs which satisfied all three conditions were accepted, while all the remaining pairs were classified as "other pairs."

1. Both members of the pair were mutual first-choice selections by their partners.
2. Both members indiciated they would choose the same partners again if they were to participate in another study using paired learning.
3. Both members independently judged their team as working together "successfully."

Table 40 presents the frequencies of these three conditions.

TABLE 40.--Student ratings related to successful pair determinations

	Frequency
1. Partner Selection Choices	
Both partners first choice	11
One partner first choice	4
Neither partner first choice	3
2. Select Same Partner Again	
Both yes	10
One yes, one no	4
Both no	4
3. Rating On Working Together As Team	
Both rate well	13
One well, one poor	5
Both poor	0

From these ratings the 18 pairs were divided into 7 "successful" pairs and 11 "other" pairs. It was assumed the successful pairs would be the best approximation of a "traditioned" pair and derive the greatest benefits from paired interaction. The successful pairs included three male pairs and four female pairs.

In order to examine the successful pairs and individuals, their background measures were compared to determine if both groups had equal ability. The results are presented in Table 41.

TABLE 41.--Comparisons of background measures for successful pairs and individuals

Background Measure	Successful Pairs	Individuals	F Ratio
Course Grades	n = 14 M = 2.14 sd = .66	n = 17 M = 2.00 sd = 1.22	F = .15
SCAT Verbal %	n = 13 M = 56.08 sd = 27.02	n = 13 M = 58.92 sd = 24.75	F = .08
SCAT Quant %	n = 13 M = 48.39 sd = 28.75	n = 13 M = 59.77 sd = 15.30	F = 1.59
Math I (Computation)	n = 12 M = 49.08 sd = 27.80	n = 14 M = 58.00 sd = 23.71	F = .78
Math II (Problem Solving)	n = 12 M = 50.58 sd = 26.26	n = 14 M = 58.79 sd = 16.25	F = .95
Algebra I Coop. Math Test	n = 14 M = 54.93 sd = 22.96	n = 17 M = 43.06 sd = 26.16	F = 1.76

Examination of Table 41 indicates that there are no significant differences in ability or achievement between the successful pairs and individuals.

These two groups were compared on the performance variables recorded during the study. The null hypothesis that there are no significant differences for any of the variables was adopted as usual and the .05 level of significance was predetermined. In all cases the F value was computed using the BMD computer program for a one-way analysis of variance. Table 42 shows the results of comparing these successful pairs with the individuals.

TABLE 42.--Comparisons of performance variables between successful pairs and individuals

Performance Variable	Successful Pairs	Individuals	F Ratio
Final Exam Scores	n=14 M=11.38 sd=2.74	n=18 M=12.56 sd=3.40	F=1.16
Daily Quiz Scores	n=7 M=8.57 sd=.98	n=18 M=8.28 sd=3.21	F=.06
Criterion Scores	n=7 M=11.71 sd=2.56	n=18 M=11.28 sd=2.80	F=.13
Number Questions Answered Correct	n=7 M=82.14 sd=6.47	n=18 M=82.22 sd=11.12	F=.00
Number of Errors	n=7 M=22.71 sd=6.16	n=18 M=25.06 sd=7.58	F=.53
Total Program Time (Minutes)	n=7 M=226.7 sd=34.64	n=18 M=238.6 sd=52.94	F=.30
Instruction Time (Minutes)	n=7 M=90.2 sd=24.1	n=18 M=104.2 sd=28.8	F=1.29
Problem Time (Minutes)	n=7 M=55.6 sd=13.0	n=18 M=61.5 sd=21.2	F=.47
Preview Latency (Minutes)	n=7 M=13.9 sd=3.86	n=18 M=15.1 sd=5.57	F=.28

TABLE 42.--Continued

Performance Variable	Successful Pairs	Individuals	F Ratio
Criterion Latency (Minutes)	n=7 M=13.3 sd=5.20	n=18 M=16.3 sd=9.32	F=.65
Quiz Latency (Minutes)	n=7 M=11.9 sd=3.64	n=18 M=11.14 sd=7.08	F=.02
Preview Confidence	n=7 M=70.71 sd=16.85	n=18 M=63.06 sd=13.87	F=1.37
Criterion Confidence	n=7 M=78.86 sd=19.63	n=18 M=77.61 sd=12.72	F=.04
Quiz Confidence	n=7 M=80.29 sd=16.18	n=18 M=73.78 sd=13.60	F=1.04

Examination of Table 42 shows no significant differences for any of the performance variables. It is perhaps interesting to notice that the successful pairs performed "better" than the individuals on eleven of the fourteen variables measured.

Question 14

How do the "successful" pairs compare with the "other pairs" in the performance variables?

Various techniques have been used in forming pairs, including random selection, matched assignments, or mutual choice. Does the method of pair formation make any difference? Assuming those defined as "successful" pairs represent "ideal" teams, while the others had certain qualities which made them slightly less desirable, the author chose to compare the two groups in order to detect any differences in performance which might arise as a result of the type of pair involved. Table 43 shows the comparison of the background variables for the two groups.

TABLE 43.--Comparisons of background measures between successful pairs and other pairs

Background Measures	Successful Pairs	Other Pairs	F Ratio
Course Grades	n=14 M=2.14 sd=.66	n=18 M=2.21 sd=.86	F=.06
SCAT Verbal %	n=13 M=56.08 sd=27.02	n=17 M=59.88 sd=23.12	F=.71
Math I (Computation)	n=12 M=49.08 sd=27.80	n=16 M=59.94 sd=23.69	F=1.24
Math II (Problem Solving)	n=12 M=50.58 sd=26.26	n=16 M=58.50 sd=20.72	F=.80
Algebra I (Coop. Math Test)	n=14 M=54.93 sd=22.96	n=18 M=47.32 sd=23.11	F=.88

Table 43 indicates there are no significant differences between the "successful" paired members and the "other" paired members. It is interesting to observe that the "other" pairs scored higher on five of the six background measures.

These two groups were also compared on the performance variables recorded during the program. As before, the null hypothesis was that there were no differences between the two groups for any of the variables. Table 44 presents the results of these comparisons.

TABLE 44.--Comparisons of performance variables between successful pairs and other pairs

Performance Variables	Successful Pairs	Other Pairs	F Ratio
Final Exam Scores	n=14 M=11.36 sd=2.74	n=22 M=11.86 sd=3.54	F=.21
Daily Quiz Scores	n=7 M=8.57 sd=.97	n=11 M=8.36 sd=2.77	F=.04
Criterion Scores	n=7 M=11.71 sd=2.56	n=11 M=12.27 sd=3.29	F=.14
Number Questions Answered Correctly	n=7 M=82.14 sd=6.47	n=11 M=84.46 sd=15.20	F=.14
Number of Errors	n=7 M=22.57 sd=5.86	n=11 M=21.73 sd=7.53	F=.06
Total Program Time (Minutes)	n=7 M=226.71 sd=34.64	n=11 M=241.91 sd=50.24	F=.49
Instruction Time (Minutes)	n=7 M=90.26 sd=24.09	n=11 M=99.35 sd=32.71	F=.40
Problem Time (Minutes)	n=7 M=55.63 sd=13.07	n=11 M=60.93 sd=17.61	F=.45
Preview Latency (Minutes)	n=7 M=13.96 sd=3.86	n=11 M=16.22 sd=5.62	F=.01

TABLE 44.--Continued

Performance Variables	Successful Pairs	Other	F Ratio
Criterion Latency (Minutes)	n=7 M=13.29 sd=5.20	n=11 M=15.42 sd=5.47	F=.67
Quiz Latency (Minutes)	n=7 M=11.87 sd=3.64	n=11 M=12.68 sd=5.59	F=.11
Preview Confidence	n=7 M=70.71 sd=16.85	n=11 M=75.82 sd=16.42	F=.41
Criterion Confidence	n=7 M=78.86 sd=19.63	n=11 M=87.91 sd=16.10	F=1.14
Quiz Confidence	n=7 M=80.29 sd=16.18	n=11 M=87.09 sd=13.35	F=.95

Although no significant differences were determined in Table 40, it is interesting to notice that the "successful" pairs scored better on all of the six _time_-related variables, while the "other" pairs scored better in _achievement_ and _confidence_ variables.

Question 15

How do pairs and individuals compare when performing the "memorization" tasks?

Much has been discussed in the literature about the nature of the learning task related to work in small groups. The most common belief is that the advantages of teamwork only become apparent in the more difficult tasks. In an attempt to verify this conjecture, the author divided the materials in the program into "memorization tasks" and "algorithmic tasks," as described in Chapter III. Fourteen concepts were classified as memorization and nine were algorithmic. The pairs and individuals were compared on their performance in these particular tasks. It was expected that the memorization tasks were relatively "easier" and that pairs and individuals should achieve equally well for these materials. Table 45 presents the performance comparisons between the pairs and individuals on only the memorization tasks, where all scores were computed per concept (as opposed to total scores, so that n = 252 = 14 tasks X 18 subjects).

TABLE 45.--Comparison between all pairs and all individuals on memorization tasks

Performance Measure	Pairs	Individuals	F Ratio
Final Exam Scores	n = 36 M = 7.83 sd = 2.34	n = 18 M = 7.89 sd = 2.25	F = .01
Daily Quiz Scores	n = 252 M = .36 sd = .48	n = 252 M = .36 sd = .48	F = .01
Criterion Scores	n = 252 M = .52 sd = .50	n = 252 M = .50 sd = .50	F = .39
Preview Scores	n = 252 M = .47 sd = .50	n = 252 M = .38 sd = .49	F = 4.31
Number Questions Answered Correct	n = 252 M = 3.37 sd = 2.05	n = 252 M = 3.29 sd = 1.97	F = .20
Number of Errors	n = 252 M = .95 sd = 1.28	n = 252 M = 1.09 sd = 1.51	F = 1.24

TABLE 45.--Contintued

Performance Measure	Pairs	Individuals	F Ratio
Problem Time (Minutes)	n = 252 M = 2.12 sd = 2.11	n = 252 M = 2.15 sd = 2.05	F = .01
Criterion Latency (Seconds)	n = 252 M = 37.46 sd = 41.29	n = 252 M = 39.52 sd = 50.99	F = .25
Quiz Latency (Seconds)	n = 252 M = 29.04 sd = 23.92	n = 252 M = 26.73 sd = 32.67	F = .82
Criterion Confidence	n = 252 M = 3.80 sd = 1.49	n = 252 M = 3.45 sd = 1.54	F = 6.57
Quiz Confidence	n = 252 M = 3.37 sd = 1.39	n = 252 M = 3.29 sd = 1.49	F = 11.72

Examination of Table 45 reveals that the pairs had a significantly higher (.05 level) confidence on the criterion and quiz frames as well as the preview scores. There were no other significant differences, although it should be observed that the pairs scored "higher" on eight of the eleven variables compared.

Question 16

How do pairs and individuals compare when performing "algorithmic" tasks?

The nine algorithmic tasks were intended to provide more difficult problems since they required a method or procedure as well as memory in order to derive the correct solution. It was expected that the pairs might perform better on these more difficult tasks. Table 46 presents the comparison results between the pairs and individuals only on the algorithmic tasks, where data was computed per concept, so that n = 162 = 9 tasks X 18 subjects.

TABLE 46.--Comparison between all pairs and all individuals on algorithmic tasks

Performance Measures	Pairs	Individuals	F Ratio
Final Exam Scores	n = 36	n = 18	
	M = [illegible]	M = 4.61	F = 2.20
	sd = 1.76	sd = 1.91	
Daily Quiz Scores	n = 162	n = 162	
	M = .38	M = .36	F = .05
	sd = .49	sd = .48	
Criterion Scores	n = 162	n = 162	
	M = .52	M = .48	F = .60
	sd = .50	sd = .50	
Preview Scores	n = 162	n = 162	
	M = .27	M = .37	F = 3.64
	sd = .45	sd = .48	
Number Questions Answered Correct	n = 162	n = 162	
	M = 4.04	M = 4.03	F = .00
	sd = 3.51	sd = 3.36	
Number of Errors	n = 162	n = 162	
	M = .98	M = 1.09	F = .59
	sd = 1.31	sd = 1.30	
Problem Time (Minutes)	n = 162	n = 162	
	M = 3.16	M = 3.49	F = 1.49
	sd = 2.15	sd = 2.74	
Criterion Latency (Seconds)	n = 162	n = 162	
	M = 38.98	M = 47.26	F = 3.38
	sd = 31.21	sd = 48.16	

TABLE 46.--Continued

Performance Measures	Pairs	Individuals	F Ratio
Quiz Latency (Seconds)	n = 162 M = 37.27 sd = 31.56	n = 162 M = 34.71 sd = 32.27	F = .52
Criterion Confidence	n = 162 M = 3.47 sd = 1.58	n = 162 M = 3.25 sd = 1.62	F = 1.48
Quiz Confidence	n = 162 M = 3.57 sd = 1.36	n = 162 M = 3.07 sd = 1.40	F = 10.61

Examination of Table 46 reveals that the pairs were significantly (at .05 level) more confident that the individuals on the daily quiz. It is interesting to notice that pairs scored "better" on eight of the eleven variables compared.

Questionnaire

The results of the student attitude questionnaire are shown in Table 47. The number of the subjects selecting the various alternatives is shown for each question.

TABLE 47.--Pair and individual responses on questionnaire

	Pairs	Individuals
1. Your personal reaction toward using computers for instruction is		
a. you enjoyed it very much	11	7
b. you felt it was O.K.	16	7
c. you didn't particular enjoy it	8	4
d. you definitely disliked it	1	0
2. While taking the program, the computer made you feel		
a. very relaxed and at ease	11	5
b. moderately relaxed	23	8
c. somewhat tense	2	5
d. very tense and not at ease	0	0
3. When taking the lessons, you felt		
a. you had to work slower than you wanted to	10	5
b. you worked at the right speed	15	10
c. you had to work faster than you wanted to	11	3
4. If you had a choice as to how the material would be presented, you would choose		
a. a good teacher	16	8
b. a good textbook	2	1
c. a computer presentation	15	8
d. other (please specify)________	3	1
5. The most undesirable factor of the computer was		
a. there was no teacher to explain things	4	3
b. you could not look back at previous materials	22	11
c. you could not correct errors	1	3
d. the computer went too slow	4	1
e. other (please specify)________	5	0
6. The most desirable feature of the computer was		
a. it didn't go too fast and leave you behind	6	3
b. you were not embarassed when you made mistakes	7	4
c. it told you immediately when you were wrong	9	1
d. it was interesting and fun to work with	11	10
e. other (please specify)________	3	0

TABLE 47.--Continued

	Pairs	Individuals
7. In general, you feel that the experiment was		
a. very interesting and enjoyable	16	12
b. satisfactory	14	3
c. a little boring	4	3
d. a waste of class time	2	0
8. When working on the question, you		
a. always tried to answer correctly	19	12
b. tried some, but not too hard	13	4
c. really didn't try as much as you should	4	2
d. mostly guessed, since it doesn't matter	0	0
9. Generally, you found the Boolean algebra		
a. very easy	1	0
b. fairly easy	13	6
c. a little hard	19	12
d. very difficult	3	0
10. When answering questions in the material		
a. you prefer answering multiple choice questions using the pen	19	11
b. you prefer answering completion questions using the keyboard	17	7
11. Which areas were most difficult for you?		
a. mathematical logic	3	1
b. set theory	12	7
c. switching circuits	10	9
d. Boolean laws	11	1
12. Which areas were easiest for you?		
a. mathematical logic	9	7
b. set theory	2	2
c. switching circuits	23	9
d. Boolean laws	2	0
13. When answering the question, you		
a. generally answered most of them correctly	9	3
b. missed only a few	26	10
c. missed most of them, but knew a few	1	3
d. guessed most of the answers	0	2

TABLE 47.--Continued

	Pairs	Individuals
14. The hints and remarks which followed your wrong answers		
a. often helped you find the correct answer	28	15
b. rarely helped you find the correct answer	7	3
c. were a waste of time	1	0
15. How do you feel after finishing the Boolean algebra experiment?		
a. you understand this material very well	1	0
b. you were beginning to catch on to the main ideas	22	9
c. you were not quite sure you understood	11	8
d. you don't understand hardly any of it	2	1
16. In general, you feel students learn better when		
a. working in pairs	22	8
b. working individually	14	10
17. If you had a choice, you would prefer		
a. working in pairs	22	9
b. working alone	14	9
18. If you were selecting a partner in a new experiment, you would		
a. choose your best friend	8	8
b. choose someone smarter than you	3	0
c. choose someone with equal ability	23	7
d. it would not matter to you	2	3
19. (Paired students only) If you were going to work in a new pair, would you select the same partner?		
a. yes	25	
b. no	11	
20. Which do you consider the best advantage of working with a partner?		
a. partner can explain material to you	17	
b. partner makes you feel more comfortable	7	
c. partner means you don't have to work quite as hard	7	
d. other (please specify)________	5	

TABLE 47.--Continued

	Pairs	Individuals
21. Which of these do you consider the worst disadvantage of working in pairs?		
a. your partner slowed you down	7	
b. your partner worked too fast	7	
c. you and your partner disagreed too often	18	
d. other (please specify)________	4	
22. When working together		
a. you did most of the work while your partner watched	2	
b. you both worked about the same amount	34	
c. your partner did most of the work while you watched	0	
23. If you and your partner disagreed on an answer, usually you		
a. did what you wanted	1	
b. did what your partner wanted	3	
c. tried to work it out together, then answer	29	
d. gave up and guessed	3	
24. If you were to judge your pair as a learning team, you would rate yourself		
a. worked together very well	12	
b. did O.K. together	19	
c. just managed to get along	3	
d. did not work together well	2	

In order to test for differences in the attitudes between pairs and individuals, chi-square tests were made for each question. The two groups differed significantly only on question thirteen.

It is interesting to observe that in question seventeen, 14 of 36 paired members indicated they would have preferred to work individually and 9 of 18 individuals would rather have worked in pairs. As a result of these attitude differences, the subjects were divided into four categories: paired members who preferred working in pairs (n = 22); paired members who preferred working individually (n = 14); individual members who preferred working in pairs (n = 19); and individual members who preferred working individually (n = 9). Comparisons were made between these groups in order to determine any differences in attitudes. When comparing all subjects preferring to work in pairs (n = 31) against all subjects preferring to work individually (n = 23), significant differences were discovered for questions one, five, and seven. Question seven is particularly important. Table 48 shows the results.

TABLE 48.--(Question 7) General attitude toward experiment for those who preferred paired instruction and those who preferred individual instruction

Alternative	Prefer Pair	Prefer Individual
a. very interesting	13	15
b. satisfactory	12	5
c. little boring	6	1
d. waste of time	0	2

The two subjects who felt the experiment was a waste of time were partners in the same pair. These two girls were in constant conflict during the instruction and both complained about having to work together. All other comparisons between the four categories resulted in no significant differences in attitudes on the questionnaire.

CHAPTER V

DISCUSSION AND CONCLUSIONS

Introduction

This chapter is divided into four major sections.

The first section includes discussion and conclusions related to the primary question investigated in this study. The fifteen subsidiary questions concerning the different performance variables are also discussed. Finally there are brief comments regarding the student attitudes toward CAI, the Boolean Algebra program, and the practice of paired instruction.

The second section of the chapter presents a summary of the results and conclusions based upon the evidence of this study. The implications relative to CAI and future developments are briefly discussed.

The third section of the chapter lists several possible areas for further research in paired learning using a CAI system. In particular these suggestions cover the inadequacies and limitations of the present study.

Finally there is a summary of the study, including the objectives, the experimental procedures, the results, and conclusions.

The Primary Question

The basic question investigated in this study was the relative achievement on the final examination of subjects who learned and worked in pairs and subjects who worked individually. Of particular interest was the nature of paired learning when using a computer assisted instruction system as a means for presenting materials.

The results from Table 11 clearly demonstrated that within this particular study, the paired subjects and the individual subjects obtained the same level on their final examination scores. Not only were there no differences between the mean scores of the two groups, but there was a general agreement across the concept units in the test.

If these results actually reflect paired learning in general, one must conclude that paired learning is not superior to individual learning, nor is pairedlearning inferior. The fact that the paired subjects performed as well as the individuals when they had to work separately indicates that both members of the pair learned during the program. There are several possible reasons which might explain the finding of no differences between the two groups.

1. It may be that there are no significant differences in learning and final achievement between pairs and individuals when instruction is presented by CAI.

2. It may be that this Boolean algebra program and the final examination were not designed in such a way as to detect any differences which might actually be present between the two groups.
3. It may be that this particular mathematical subject matter, Boolean algebra, is by its very nature inappropriate for paired instruction.
4. The particular sample of pairs selected for the study may not have been "ideal" nor provided the expected benefits from pairing.
5. The population from which the sample was selected (basic algebra students) may have peculiar qualities affecting the experimental results. This population would probably be located on the lower half of a general mathematical ability distribution over all high school algebra students.
6. The CAI presentation, by its very nature, may have minimized the pairing effects and maximized the individual advantages, since the system was designed specifically to provide individualized instruction.

One is tempted to generalize the results and conclude that since there were no differences between the achievement of the two groups detected in this particular experiment, then within the population of high school students enrolled in first-year algebra, there would be no differences between paired and individual achievement when learning any materials presented by means of a CAI system.

Some of the options which may have affected the experimental results should be considered in more detail. The first possibility is that this particular instructional program may not have demonstrated the advantages of paired learning. The most serious limitations of this program were in content and student control. Due to the external scheduling requirements the original program was severely edited and cut to the minimum essentials, deleting some instructional frames and examples, removing many "help" frames, and eliminating the ability to review previous frames. The subjects had little control over their instruction. They could not select the amount or content of their instruction, ask for more examples, request better explanations, review previously covered materials, nor could they branch around topics they already knew. All subjects were virtually forced to take an "identical" sequence through the materials. These two factors of reduced content and limited subject control probably minimized the advantages or effects of paired learning.

Also, one must consider the possibility that the final examination questions may have been more difficult than the instructin so that a high percentage of students simply could not answer the questions. Thus the exam would not actually measure any differences due to pairing even if they were present. This conjecture is supported by the fact that subjects often missed questions on the final examination which they had answered correctly on the criterion frames (see Tables 15 and 16).

Considering the possibility that Boolean algebra is not appropriate for paired instruction, the author feels that these mathematical materials are representative of a wide range of topic Boolean algebra requires the learning of new symbols, definitions, and the ability to solve problems. These are the same tasks necessary in the majority of other mathematical subject areas. Therefore, the author does not believe that Boolean algebra was inappropriate for the study.

Another factor to be considered is the nature of the pairs. Although the sample of pairs selected for this study were probably typical, certain improvements could have been made. The random selection necessarily divided the classes in such a manner that the "best" pairing combinations were impossible. Many of the individuals would have preferred working in pairs, while some of the paired members would rather have worked individually. On the attitude questionnaire, 9 of 18 individuals indicated they would have preferred working in pairs, and 14 of 36 paired members would have chosen to work by themselves. It may be that certain types of students learn better in pairs (i.e., insecure personality) while others are superior when learning alone. An interesting study would be to investigate the possibility of allowing the subjects the decision whether to work in pairs or individually. In the present study, the subjects were allowed to select their partners from a restricted and predetermined list, but they were given no option whether to work in pairs or individually. Considering the student preferences with respect to pairing as indicated on the attitude questionnaire, the author believes the pairs could have been more ideally selected.

When considering the subject population there are two factors which may have influenced the experimental results. First, these students were enrolled in basic algebra because they were below average in mathematical skills. The fact that neither the pairs nor the individuals achieved satisfactorily on the final examination may be only a reflection of their limited ability and experience in mathematical skills. The second factor is specifically related to subjects from the University School. These students participate in many "educational experiments" during their school lifetime, and they often develop a blasé attitude toward experimental situations. As typical students, they are happy to get out of the regular classroom, and the experiment becomes a diversion or time for fun and relaxation. Many students did not really care whether they answered correctly or incorrectly simply because they knew this was an experiment and not part of their regular work.

Another consideration is that the CAI presentation may have diminished the effects of pairing by raising the individual's performance level. A well-written CAI program is designed to eliminate many of the difficulties associated with individual learning in a typical classroom or with a textbook. As a result, the individuals may have been able to learn better due to the CAI presentation, which raised their achievement to the level of the pairs. In this particular study, the author feels that conclusions cannot be made related to paired learning when other types of presentation media are used.

Another possibility related to the final examination is the "shock effect" of suddenly working individually. How is achievement affected when students who have learned and worked together for a period of time in pairs and are then suddenly thrust into a situation (the final exam) where they must perform absolutely alone? This is a new and uncertain behavior for them and their scores may be diminished as a result of this unfamiliar type of activity demanded of them. A more reliable result might have been obtained if the paired subjects were occasionally required to work individually, such as on practice problems, then later were given the opportunity to discuss the problems with their partners. This mixture of paired learning and independent practice might eliminate the sudden "shock" of having to suddenly perform alone which was the case in this experiment.

In conclusion, the fact remains that in this study using an abstract algebra program, the pairs and individuals attained equal achievement. If one can generalize the results of this study to the population, then one would conclude that when students are taught materials via CAI, paired and individual subjects learn equally well! If this be true, then the costs of operating a CAI system may be cut in half by means of paired learning, without any loss of effectiveness.

Subsidiary Questions

Question 2

Did the students learn from the Boolean algebra program?

Although the results indicated a significant increase from the preview to the criterion and final exam scores for both the pairs and individuals, the author feels that this increase is deceptive since the average score improved only by three questions. That is, if the student could answer 8 preview questions correctly, then after the program he could answer only 11 final exam questions. Secondly, both groups only answered about 50% (12 of 23) of the final exam questions correctly, which was much lower than the author anticipated.

Achievement was "measured" three times after the subject received instruction: immediately after (criterion frames), after short delay (daily quiz), and after long delay (final examination). Some unanticipated results were obtained from these measures. For both groups, the mean preview score was approximately 8 (of 23), the mean criterion score was 12, the mean daily quiz score was 8, and the mean final examination score was 12 (see Table 13 for exact means). Why did the quiz scores decline but final examination scores recover? What factors contributed to the poor reliability and lower performance on the quiz?

A detailed examination of the preview, criterion, quiz, and final examination scores for each concept unit is presented in Appendix I. This analysis shows the quiz scores made a significant drop on the following concepts: 1,2,4,5,6,11,12,14,15,17,29, and 31.

The first possible explanation for the drop in scores for these questions is that they were more difficult than the criterion and final questions. Appendix F shows the preview, criterion, quiz, and final questions for each concept. A subjective examination of the questions reveals that they are fundamentally equivalent and some are virtually identical. Thus differences in question difficulty do not explain the drop in scores.

A second plausible explanation is that the students hurried at the end of each lesson when they took the quizzes and guessed answers more frequently than before. Appendix F presents an item analysis of the questions showing the response frequencies for each alternative. By examination of these responses, the author gained some insight on why these questions were missed more frequently. If a large percentage of responses were found on an incorrect alternative, then the question was probablymissed due to a misunderstood conception. If the responses were evenly distributed between the alternatives, then the subjects were probably guessing. Using this basis for judgement, questions 1,2,4, and 29 appeared to be answered incorrectly due to misconceptions Questions 6,11,12,14,15,17, and 31 were probably missed as a result of guessing. Examination of the criterion frames for the same questions does not indicate the subjects were guessing at that point. Therefore, guessing on the quiz probably was a significant factor causing a drop in scores.

A third possible explanation is learning interference. The subjects were given instruction for aparticular concept and a criterion question followed immediately. At this point, the concept was fresh in their minds and they responded correctly. Then other concepts were presented until the lesson was completed and the subjects took the quiz. By this time, they had forgotten the concept "learned" earlier. Intervening materials and no time for practice, review, or reflection contributed to their forgetting. The possibility of learning interference is supported by the fact that there was an *increase* in scores from the criterion to quiz on *all* the concept units which immediately preceded the daily quizzes.

There are two reasons to explain why the scores recovered on the final examination. First, the students were not rushed on the final exam. They had time to think and to change answers after reflecting. Secondly, the students probably continued learning about early concepts later in the program. For example, the Null element, $\emptyset$, which was unfamiliar in the first lesson and quiz, became quite familiar in the remaining lessons, so that by the final examination the question was answered correctly.

Therefore, concerning whether the students learned from this Boolean algebra program, in spite of the fact that there appeared a "statistical" improvement in the subjects' scores, the author is reluctantly forced to conclude that most of the students did not achieve nearly as well as expected.

Question 3

How do pairs and individuals compare in achievement during the instructional phase of the program?

From the data in Table 17 and Table 19, it is obvious that the pairs and individuals demonstrated nearly equivalent performance during the program. The subjects devised a clever technique which was unanticipated by this author. Often students would look around to see another terminal on the same question. After watching their neighbor's response, they knew how to respond correctly. This type of "cheating" was discouraged, but could not be entirely eliminated. The author concludes the groups perform equally well within the learning phase.

Question 4

How does achievement during the learning phase correlate with achievement during the examination phase?

The author expected that performance variables during the program would act as reliable predictors for final exam achievement.

Table 20 indicates that the number of problems answered correctly (within the program) was significantly correlated with the quiz and final exam scores for both groups. The criterion scores correlated significantly with exam scores for the pairs, but correlated very poorly for the individuals. One possible explanation is that the paired subjects were able to recall their previous responses better than those working independently. There is no way to determine if this phenomenon is the result of a pairing effect or a result of the nature of the materials. One can only conclude that the criterion scores are fairly reliable indicators of final exam and quiz scores for the paired subjects but not for the individuals.

Question 5

What is the result when pairs are allowed to work together in a combined effort on examinations?

Must examinations always be given to students individually or can they be given to pairs of students with equal effectiveness? Although this question is not particularly important, the quizzes were included in the program to allow a comparison between being examined in a pair and being examined individually. Unfortunately the quiz scores were so unreliable they provided a very poor measure of the subjects ability. As a result the quiz scores probably do not represent a good comparison between paired testing and individual testing. The author feels this question is still unanswered.

Question 6

What is the relationship between achievement of pair members when they perform independently? Did the paired members appear to answer identically when working separately? The evidence from Table 25 and the correlation coefficient between partner scores indicates they answered somewhat independently. The most plausible explanation of this behavior is that since the final examination scores were answered correctly at approximately the 50 percent level, there must have been a great deal of guessing on at least 50 percent of the responses. Such extensive guessing would completely obscure the correlations between partners in much higher agreement than is shown in this experiment.

The differences between the paired members are also interesting. One would not expect both members of a pair to have identical scores, but this would not necessarily mean that there should be a significant difference as indicated by the t test on $F_2 - F_1$. The fact that there was such a disparity between pair scores suggests that although one member either knew or learned, he did not or could not communicate this to his partner. If one accepts the possibility that the pairs did not "communicate" very successfully, then one should consider the reasons. One possibility is the nature of the questions. Multiple choice questions allowed one partner to say "which choice" was the correct answer without explaining how he derived the solution. Thus, the student who did not understand is rewarded for a correct answer, but he doesn't know the concept. Another factor which diminishes the communication between members is built into the CAI presentation. The immediate feedback and continuation on to new materials prevents the uncertain student from stopping to ask questions since his attention is quickly focused on a new problem. The rapid and automatic presentation eliminates any time for reflection or explanations or questions between the partners, thus inhibiting the communication. While there is usually a great deal of interaction and discussion prior to answering a question, there is little time for reviewing after responding.

Question 7

How do pairs and individuals compare in the various time measures?

Timing considerations become increasingly important in modern technological education. These variables were examined carefully and extensively. The results from Table 27 demonstrate that pairs and individuals can work at the same rate using CAI presentation, in fact, the pairs actually required less time than the individuals in all time measures except one, the daily quiz latency. Apparently the pairs are able to arrive at mutual decisions as quickly as individuals.

The correlations in Table 29 are interesting. All entries indicate a positive relationship between latency time and score. This means that longer latencies are associated with higher scores.

The results of Table 30 also reflect that longer time measures correlate positively with achievement scores. No explanation could be offered for the low correlations on the criterion scores for the individual group.

All timing measures must be viewed with one consideration kept in mind. The CAI system is often almost instantaneous in sending feedback and executing the program, but there are times, depending on the number of subjects on the system, when the program moves slowly, sometimes unbearably slowly. Subjects often complained that the computer was too slow. Hence, all time measures are a combination of "subject time" plus "system time." When the "system time" percentage becomes quite large, then recorded time estimates do not actually reflect the true time necessary for subjects to proceed through the program. The system and program determine a "minimum" time that a person can complete the program. Thus those students who can work rapidly (faster than the "system time") would all finish approximately together, with the times recorded actually reflecting the system time, not the subject time. CAI is capable of presenting and responding faster than any device known other than a human brain, yet not instantaneously as many subjects would like. As measured by a CAI system, there are no differences between paired instruction and individual instruction.

The author concludes, then, that one can present instruction via a CAI system to pairs in the same time which would be required for individuals.

Question 8

How do pairs and individuals compare in the number of errors?

According to the data in Table 34, there were no differences between the number of errors made by pairs and number of errors made by individuals on the criterion frames. The mean of 22.1 and 25.1 errors over 23 questions is a pretty high error rate. There are three factors which had a tendency to produce an excess of errors. Multiple choice questions invite frequent guessing, hence an increased incidence of errors simply because students answered without deliberating. Secondly, the light-pen response mechanism did not always function properly and would sometimes record four or five incorrect responses when the student actually only responded once incorrectly. For example, one student was recorded as making eleven errors on a single 4 item multiple choice question. The third difficulty was that students often knew the correct answer but accidently placed the light pen on the screen or improperly touched the light-sensitive areas, hence recording an incorrect response. All of these factors, however, worked against both groups with equal frequency, hence the author feels confident in concluding that there is no difference between pairs and individuals on the number of errors made in the learning process.

The results of Table 32 indicate that the number of errors correlates negatively with both time measures and achievement scores. The author cannot explain why the individual correlations were not significant.

Questions 9 and 10

How do pairs and individuals compare in the confidence of their answers?

The evidence from Table 33 suggests that pairs are in fact more confident than individuals. Unfortunately, this difference seems to lose any value when the results of Table 34 indicate very little correlation between confidence and actual scores, hence being more confident doesn't appear to produce higher achievement. The weighted scores, combining correctness and confidence, did not appear to provide any better measure of a subject's understanding.

The question remains, why was the confidence rating such a poor indicator of performance? The only suggestion by this author is that the materials were of sufficient difficulty so that subjects actually thought they were correct, when in fact they were not. In order to prevent the multiple choice questions from being too easy, the author made the wrong answers seem plausible and often "looked" correct. Probably many subjects were tricked by these questions, thus they answered with high confidence but obtained low achievement. The author feels the question of confidence should be further investigated using a different type of program.

Question 11

Is there any experimental evidence which supports the claim that paired interaction consists of pooled information?

The results from Table 33 indicate that there was no difference in preview scores between pairs and individuals. There are two factors to consider: were the preview scores actually a measure of the pooling effect and were the preview frames sensitive enough to detect any differences between the two groups?

One must take into consideration that some instruction did precede preview frames, and although each preview frame was supposed to introduce a new concept, there was definitely some relationship between concepts. In fact, 39% of the preview frames were answered correctly as opposed to the 25% which would be expected as a result from random guessing. There is no evidence of pooling from the data.

Question 12

Is there any experimental evidence which supports the claim that paired interaction consists of a generation of new knowledge?

The results of Table 39 indicate that pairs do not in fact generate more new insights than individuals. The "differential" scores were unexpectedly low, averaging only 6 out of 23. This is a result of higher than anticipated preview scores and lower criterion and final exam scores.

Thus, the author feels that this measure does not provide any conclusive evidence related to the interaction between pairs.

Question 13

Assuming that certain selected pairs may be described as "successful pairs," how do these pairs compare with the individuals on the performance variables?

The author selected the "successful" pairs based upon a set of subjective criteria. Other methods may have provided better choices. The pairs were not determined until after the conclusion of the experiment, hence it was impossible to directly observe these pairs in action to verify that they did work together efficiently. According to the results from Table 42, the successful pairs performed no better than the individuals.

Question 14

How do "successful" pairs compare with "other" pairs in the performance variables? The results from Table 44 indicate no no significant differences between the successful pairs and the other pairs. There are several possible explanations for these results.

1. The pairing variable (i.e. how pairs are formed) does not make any difference in achievement.
2. The method of dividing the pairs into "successful" and "other" was not very effective.
3. The pairs did not have enough time in the experiment for the "beneficial" and "detrimental" effects to become measurable.

The author intuitively rejects the first option and leans toward the latter two. The question of the pairing variable needs further investigation. In conclusion, when using CAI presentation the pairing variable did not seem to influence achievement.

Questions 15 and 16

How do pairs and individuals compare when performing the "memorization" tasks and "algorithmic" tasks?

Clearly from Tables 45 and 46 there is no difference between the pairs and individuals for either the memorization tasks or the algorithmic tasks, except for the criterion and quiz confidences. The concepts were subjectively classified by the author into the memorization and algorithmic categories with the assumption that those problems requiring an algorithm or procedure to obtain a solution would be more difficult. Examination of the criterion and final examination profiles (Tables 19 and 12) for those algorithmic tasks (concept units 5, 8, 11, 14, 15, 17, 20, 31, 32) indicate these were not, in fact, the most frequently missed problems. In fact no patterns could be found related to concept and frequency missed.

Hence "problem difficulty" was not necessarily related to the memorization-algorithmic classification. On the final examination, both groups answered 55% of the memorization problem while for the algorithmic, the pairs answered 42% and the individuals 51%.

The author concludes that the algorithmic-memorization division was not a reliable measure of task difficulty and hence no differences were found. In future studies, more specific attention should be placed upon construction tasks with varing degrees of difficulty.

Questionnaire

1. Attitudes toward CAI

The attitude questionnaire and discussions with the subjects revealed important attitudes concerning the advantages and disadvantages of learning on a CAI system.

The majority of the students who participated in the study indicated they enjoyed the opportunity to use the CAI system and felt they gained from the program. Only 2 out of 54 said it was a waste of time. Given a choice between CAI presentation and a good teacher, about half preferred CAI. The subjects indicated the most undesirable feature of this program was that they were not permitted to look back at previous materials. When asked about the most desirable feature of CAI, the majority indicated it was interesting and new.

2. Attitudes toward Boolean Algebra

Most of the students indicated that the Boolean algebra was somewhat difficult for them, but they were finally beginning to grasp the main ideas presented in the program. They related the set theory most difficult and switching networks the easiest, although many felt just the opposite.

3. Attitudes toward Pairing

The subjects were divided in their attitudes toward the use of paired learning. About 30 felt that students learn better in pairs and would prefer working within a pair while 22 would have rather worked individually. Half the individuals would have chosen to be in the paired group. Most of the subjects indicated that if they were to select a partner, they would choose someone with equal ability, probably their best friend.

After the conclusion of the experiment, the paired members were asked to judge themselves. Ten of 34 felt they would select a different partner, yet 31 of 36 said their pair worked very well or satisfactorily during the program. The greatest advantage in pairing, they felt, was that their partner could provide explanations. The disadvantages were that there was frequent disagreement or their partner slowed them down too much.

Implications

The results from this study indicate that in every respect, pairs and individuals perform equally on a CAI presented program. If, in fact, this conclusion is true, then the implications for CAI research are profound.

The first implication is that paired instruction provides a technique which produces equivalent achievement. This means that two persons working together can learn some areas of mathematics as well as when working individually.

The second implication is that paired instruction provides a technique for increasing instructional efficiency. Since pairs learn equally well in the same amount of time, then twice the number of students may be taught using this method. In effect, the cost of instruction by CAI may be exactly cut in half. With the rising population and educational costs, any increases in efficiency are major considerations in modern education, and the technique of paired instruction, as a means of increasing the efficiency and decreasing the cost, should be fully investigated.

Summary

The general objective of this study was to investigate a technique which might improve the effectiveness and efficiency of teaching when using a CAI system. The technique under consideration was the use of paired learning teams during instruction. A primary question and fifteen subsidiary questions related to paired instruction were investigated.

1. The primary question under consideration was the comparison of final achievement of students who learn Boolean algebra in pairs with students who learn individually when instruction is presented by means of an IBM 1500 CAI system and all subjects are tested individually.

The fifteen subsidiary questions were:

2. Do the subjects learn Boolean algebra from this CAI program?

3. How do pairs and individuals compare in achievement during the learning phase of the program?

4. How does learning phase achievement correlate with examination phase achievement?

5. What is the result when pairs are allowed to work together in a combined effort during an examination?

6. What is the relationship between partner scores when they are required to perform independently?

7. How do pairs and individuals compare in various time measures including total instructional time and question latency time?

8. Do pairs and individuals make the same number of errors when answering questions? How are the errors related to the other performance variables?

9. How do pairs and individuals compare in the confidence of their answers?

10. How are the confidence measures related to the other performance variables?

11. Is there any evidence which supports the claim that paired interaction consists of pooling of information and knowledge?

12. Is there any evidence which supports the claim that paired interaction consists of a generation of new knowledge not possessed by either member prior to the interaction?

13. Assuming certain pairs may be defined as "successful pairs," how do these compare with the individuals in the performance variables?

14. How do the "successful pairs" compare with the "other pairs" in the performance variables?

15. How do pairs and individuals compare in the performance variables for "memorization tasks"?

16. How do pairs and individuals compare in the performance variables for "algorithmic tasks?"

These questions were investigated by comparing the performance of a group of pairs with a group of individuals on a Boolean algebra program presented by a Computer Assisted Instruction system.

The experiment was conducted at the Florida State University CAI Center which incorporates an IBM 1500 system. Thirty student terminals equipped with cathode-ray tube presentation and keyboard or light-pen response modes were available for the study.

The material used in the experiment was a linear program on Boolean algebra presented in the context of mathematical logic, set theory, and electric switching networks. The program was divided into five lessons, each requiring approximately forty minutes. These five lessons included 23 separate "concept units." Each concept unit represented a basic idea or skill to be taught to the students. At the beginning of each concept unit was a "preview frame" which tested the subject to determine if he had previously learned that concept. After the preview frame followed instruction, examples, and practice problems related to the concept. Finally, a "criterion frame" examined the student to determine if he had learned the particular concept. At the end of the daily lesson, there was a quiz, with questions covering all the concepts presented during that lesson. After all five lessons were completed, the subject took a final examination including 23 questions, one for each concept in the program. On each preview, criterion, and quiz question the students were required to indicate the "confidence" or "certainty" of their answer. Confidence ratings were made on a 1-5 scale where a 1 indicated the student was guessing and a 5 indicated he was 100 percent certain of his answer. The subject materials were divided into two types of tasks often encountered in mathematical instruction. These were "memorization tasks" which require remembering definitions or symbols and "algorithmic tasks" which demand learning a process or procedure to solve a given problem. The entire program included 23 preview frames, 128 practice problems, 23 criterion frames and 23 daily quiz questions.

The 54 subjects participating in the study included two sections of Basic Algebra I from the University School located near the CAI Center. There were 27 males and 27 females; 17 ninth graders, 24 tenth graders, 10 eleventh graders, and 3 twelfth graders; and they had a mean age of 15.4 years.

The objective was to form pairs which approximate traditioned groups as defined by Lorge, since this type of team should benefit most from paired instruction. The subjects were randomly divided into two groups: 36 in the paired group and 18 in the individual group. The members in the paired group listed their first five preferences for partners and the author formed pairs based on the mutual selections.

The experiment was conducted in April, 1969, and lasted a total of nine days. The first day was used to describe the experiment, explain the use of the CAI equipment, and make pair selections. The students came to the CAI Center for the second, third, and fourth days to take the first three lessons. The fifth and sixth days were used for make-up work. The seventh and eighth days covered the last two lessons and on the ninth day all subjects took a final examination and attitude questionnaire. During the five lessons the paired students worked together on all materials and daily quizzes, but they worked independently on the final examination.

The final examination included 23 multiple-choice questions which were highly similar to the preview, criterion, and quiz questions. The test was administered in the normal classroom and was in printed form. An attitude questionnaire was given to determine the subjects' opinions toward CAI instruction, Boolean algebra, and paired instruction.

The reliability of the criterion scores was .59 for the paired group and .47 for the individuals. For the daily quiz scores, it was .12 for the pairs and .62 for the individuals. For the final examination it was .58 for the pairs and .61 for the individuals.

In a comparison of the background ability and achievement of the two groups, no significant differences were found for the following measures: first semester course grades, SCAT verbal %, SCAT quantitative %, Florida State-wide Achievement tests (computation and problem solving), and cooperative mathematics test (Algebra I).

The results related to all sixteen questions include:

1. When comparing the two groups on final achievement, the mean final examination score for pairs was 11.67 and for individuals was 12.56 (out of total 23). The difference was not significant at the .05 level. The groups also were in agreement in performance across the individual concept units.

2. The mean preview score was 9.06 for pairs and 8.67 for individuals. The mean criterion score was 12.06 for pairs and 11.28 for individuals. The mean quiz score was 8.44 for pairs and 8.28 for individuals. There was a significant increase from the preview questions to the criterion and final examination questions for both groups, however, there were no differences between the preview scores and daily quiz scores.

3. There was no significant difference between the pairs and individuals on the number of practice problems solved correctly (pairs = 83.56 and individuals = 82.22) or on the criterion frame scores.

4. The correlations between number of practice problems solved correctly and criterion scores with daily quiz scores and final examination scores were positive and significant at the .05 level for the paired group. The criterion scores did not correlate significantly for the individuals.

5. No significant differences were found between the two groups in daily quiz scores.

6. The correlation between partner scores on the final examination was .197 indicating they answered relatively independently. The difference between partner scores, $F_2 - F_1$, was significant. On the final examination partners had identical answers on 59% of the questions and disagreed on 41% of the questions.

7. The average total instructional time was 236 minutes. The mean lesson time was 47 minutes. The instruction time per concept unit was 4.4 minutes. The mean preview, criterion, and quiz latencies were 38 seconds, 33 seconds, and 30 seconds respectively.

   There were no significant differences between the two groups for these time measures: total program time, instructional time, time for solving practice problems, preview latencies, criterion latencies, or quiz latencies. The paired group required less time for every measure except the quiz latencies.

8. The mean number of errors recorded on the criterion frames was 22.1 for pairs and 25.1 for individuals. This difference was not significant at the .05 level.

9. The pairs were significantly more confident than the individuals on the preview frames and quiz frames.

10. Confidence ratings did not correlate significantly with scores in general. For the paired group on the criterion frames there was a significant correlation.

11. There was no evidence of "pooling" since there were no significant differences between the groups on mean preview scores.

12. There was no evidence that pairs "generated" more information than individuals. A "differential score" is when the student missed the preview frame but answered the examination correctly. The mean preview-criterion differential score was 6.11 for the pairs and 5.50 for individuals. The mean preview-final differential score was 6.64 for the pairs and 7.17 for the individuals. These differences were not significant.

13. The paired subjects were classified as "successful pairs" and "other pairs" where "successful pairs" had mutual first choice partner selections, where both members would choose the same partner again, and both members judged their team as working well together. There were no significant differences between the successful pairs and individuals on any of fourteen performance variables.

14. There were no significant differences between the successful pairs and other pairs on the fourteen performance variables.

15. There were no significant differences between the two groups for the "memorization" tasks on the "algorithmic" tasks.

The attitude questionnaire revealed that 14 of 36 paired members preferred to work individually while 9 of 18 individuals would rather have been in the paired group.

The overall conclusion is that paired students can learn Boolean algebra as well as individual students when the materials are presented by a CAI system. The implications from this conclusion are that the educational costs for computer assisted instruction may be halved and that the efficiency for using available CAI facilities may be doubled by using the technique of paired instruction.

Suggested Topics for Further Research

1. Further investigation of pair versus individual achievement using CAI presentation. In order to demonstrate that pairs and individuals do, in fact, learn equally well and attain equivalent achievement levels, more research must be conducted relative to the type of instructional program and the nature of the subjects. These comparisons must utilize a full spectrum of instructional programs which vary in subject content, presentation style, and level of difficulty. Subjects taking these programs should represent different segments of the educational population, ranging from pre-school to

graduate level. Only by a thorough investigation can this question be conclusively determined so that paired CAI instruction can be justified.

2. Investigation of the pairing variable. There have been no careful investigations which examine the type of person which benefits most from paired instruction. The attitude questionnaire indicated that some personalities apparently prefer to learn in a paired situation while others would rather work independently. Identification of these persons with any defining characteristics might provide for more efficient learning for all subjects. Allowing subjects the freedom to decide whether to work in pairs or individually and to form pairs by mutual choice could provide insights into the nature of the pair-choice personality and partner selection. If pairing is to be used in education, the pairing variable must be investigated.

3. Investigations with student-controlled instruction. CAI programs range from the inflexible linear program to highly complex programs offering many branching options and extensive student control over the instruction. The CAI programs used in this study was linear with minimal variation or flexibility, hence pairs and individuals are forced to take virtually identical programs. What would be the result if comparisons were made when subjects could select the amount, difficulty level, and topic areas in their instruction? Would pairs require less time and take shorter paths? To determine the most efficient method, programs which incorporate student control over instruction must be investigated.

4. The investigation of task difficulty. There is some evidence in the literature that the advantages of paired

learning do not become apparent except when the learning tasks are sufficiently difficult. A more carefully designed program should be constructed specifically with various levels of task difficulty. Using this type of program, comparisons between pairs and individuals should be made relative to the task difficulty level. Perhaps the optimal instructional strategy would provide individual instruction except for the more difficult tasks, when the class would form into pairs, hence pairing would be a technique dependent upon difficulty of materials.

5. Investigation of pair-individual alternation. There is no reason to assume that learning entirely within the paired setting is an efficient technique. One would think some combination of paired learning and individual practice would provide the most effective system. The pair-individual mixture should create the situation where subjects do not become totally dependent upon their partners nor allow their partners to carry the burden of learning, but are constantly reminded of their individual responsibility. Using this technique, the individual obtains feedback on his own weaknesses and inabilities, then has an opportunity to discuss them with his partner. This method should be investigated in order to obtain the most efficient instruction.

In short, when educators are attempting to determine the most efficient and effective instructional strategy, the author feels these insights should be considered when using paired learning:

1. Not all students benefit from paired instruction. It would be unwise to decide to utilize either all pairs or all individuals as a teaching strategy.

2. Not all subject materials or learning tasks should be in a paired setting. For some situations, individuals instruction is best while in other cases, paired instruction may be superior.

3. If pairing is to be employed, exclusively learning in pairs with no opportunity for individual practice may not be most effective. Highest achievement is probably obtained with a mixture of paired and individual learning.

APPENDIX A

PAIR SELECTION SHEETS

THIRD PERIOD

YOUR NAME____________________

Below are two lists. One list includes all students who will work individually and the other list includes those who will work together in pairs. Each person in the "pair" group must select his own partner. Think of five persons on this list that you would like to work with and feel as though you could work well with. Mark the numbers 1, 2, 3, 4, and 5, beside the names indicating your first choice, second choice, etc. Partners will be assigned as fairly as possible on the basis of your selections. Once teams have been assigned there will be no changing.

Individuals

Cashin, Mike
Clayton, Bev
Cole, Jimmie
Herald, Margaret
Hines, Janet
Johnson, Daphnie
McDonald, Lowell
Scott, Randy
Strickland, Vicki

Pairs

Beam, Mitchell
Braxton, Quentin
Duff, Vic
Eubanks, Melissa
Fultz, Betty Neil
Gordon, Debra
Heath, Lyn
Hilbert, Margaret
Kilenyi, Ethel
Lewis, Randy
Moorhead, Nancy
Oppenheimer, Donna
Owens, Regina
Riley, Charles
Smith, Shauna
Swartz, Freddie
Tucker, Sonny
West, Edwina

FOURTH PERIOD YOUR NAME________________________

Below are two lists. One list includes all students who will work individually and the other list includes those who will work together in pairs. Each person in the "pair" group must select his own partner. Think of five persons on this list that you would like to work with and feel as though you could work well with. Mark the numbers 1, 2, 3, 4 and 5 beside the names indicating your first choice, second choice, etc. Partners will be assigned as fairly as possible on the basis of your selections. Once teams have been assigned there will be no changing.

Individuals

Curry, Katy
Herold, Mary
Herp, Susie
Hilbert, Rusty
McCollum, Judy
Poppell, Linda
Strickland, Tom
Swartz, Jeffrey
Young, Kimber

Pairs

Albertson, Roy
Chandler, Craig
Dunlop, Donnie
Earle, Eric
Featherstone, George
Flowers, Woody
Fulford, Lee
Graddy, Alan
Fulford, Lee
Graddy, Alan
Gray, Donna
Herp, Sandy
Langston, Alan
Martin, David
Mitchell, Frank
Mobley, Melvin
O'Brien, Susan
Ott, Hugh
Schultz, Diane
Sheward, Sheri
Thorpe, Jean
Williams, Suzanne

APPENDIX B

INSTRUCTION HANDOUT

Mr. Bill Love
CAI Center
F.S.U.
599-3660

I. PURPOSE OF EXPERIMENT

This experiment is an investigation of paired learning versus individual learning of a Boolean Algebra program presented by computer-assisted instruction.

II. CALENDAR

A. Week

Friday	April 25	Introduction (Univ. School)
Monday	April 28	Block 1 (CAI Center)
Tuesday	April 29	Block 2 (CAI Center)
Wednesday	April 30	Block 3 (CAI Center)
Thursday	May 1	Block 4 (CAI Center)
Friday	May 2	Block 5 (CAI Center)
Saturday	May 3	Make-up (CAI Center)
Monday	May 5	Final Exam (University School)

B. Daily

3rd Period Class	4th Period Class
10:10-Out 2nd Period	11:10-Out 3rd Period
10:15-Arrive CAI--Begin	11:15-Arrive CAI--Begin
11:05-End Block--Quiz	12:05-End Block--Quiz
11:10-Leave CAI	12:10-Leave CAI
11:15-Begin 4th Period	Lunch

III. LEARNING MATERIALS

A. Content: The learning materials include an introduction to Boolean Algebra in the context of mathematical logic, elementary set theory, and electrical switching networks.

B. Blocks: The program is divided into five blocks, one block for each period of instruction. You should be able to finish the block in forty minutes if you work at a steady pace.

C. Concept Units: The course contains 25 concept units, each unit consisting of a Preview Frame, Instruction, Multiple Choice Problems, then a Criterion Frame. The preview frame is to determine if you know a concept before you receive any instruction. If you cannot answer the preview frame, don't waste time--just select the best answer. The criterion frame is like a test question. It is supposed to indicate how much you learned during the instruction. Answer criterion frames very carefully!

D. **Confidence Scales:** On the preview and criterion frames you will be asked to indicate the confidence of your answer. This is a five point scale and it is important that you clearly understand the meaning of each of the five ratings on the scale.

A rating of:

1 means that you cannot eliminate any of the answers and are forced to make a guess from the four choices.

2 means that you are certain that one choice is wrong and you are forced to guess from the three remaining choices.

3 means that you are certain that two of the choices are wrong, and you are forced to guess from the two remaining choices.

4 means that you are certain that three of the choices are wrong, and you select the remaining choice because you are not certain that it is wrong.

5 means that you are certain of the correct answer and did not need to consider any of the remaining choices.

Occasionally during each session we will ask you to express your feelings about the materials you have gone through.

E. **Exams:**

1) Daily Quiz. At the end of each block you will take a short quiz (4 or 5 questions) covering the concepts presented in that block. There are five daily quizzes.

2) Final Exam. After finishing the course all students will take a final exam consisting of 50 multiple choice questions covering the entire program.

F. **Hints:** Take your time when reading the materials on the screen. Read it several times if necessary, however, don't waste time. You may feel the desire to take notes during the program, however, this will only slow you down and will not help on the exams. We will provide you with paper to work out problems but please do not take notes. Avoid errors as much as possible. With multiple choice questions it is tempting to guess rather than working out the problem. Wrong answers are recorded and count against you. When a complex problem is given, DO NOT try to solve it all in your head--work it out on paper before answering. If you do make an incorrect choice, follow any hints given and double check your work.

IV. SCHEDULE PROBLEMS

A. **Location of CAI Center:** The CAI Center is located in the basement of Tully Gym. about a block from the University School.

Enter the side door (near archery field) and follow signs into the basement. Go directly from your 2nd or 3rd class period to Tully Gym. Do Not go to Mr. Goff's classroom. Time is very important.

B. If you work at a steady pace, you should finish the lesson for the day. Since all of you will be working at your own pace, it is possible that some of you may not be finished when it is time to leave. This again points out the need to get to the CAI Center as soon as possible so that you will not have to make up the time after school or on Saturday. We have set up the sessions to minimize this possibility. However, if you do not finish the block of instruction during the class period, then Mr. Love will see about scheduling a make-up time.

V. OPERATING THE CAI TERMINAL

A. Student Number: Before you begin this course you will be assigned a student number, such as S23 or t17. This number is registered in the computer and you must use it for the duration of the instruction, so do not forget it.

B. Terminals: There are 20 student terminals at the CAI Center, each terminal consisting of a television-typewriter combination. You will be assigned a particular terminal where you should work. Do not change terminals during the week. Each terminal will have the names of students working there.

C. Response Modes: A student can "communicate" with the system in two ways:

1) By pressing the screen with a light pen attached to the cable on the right of the set,

2) By typing messages on the keyboard. These two forms of communication are called response modes. The computer will specify which type of response mode the student must use, that is, either light pen or keyboard. When the computer is ready to accept your response, either a "P" or a "K" will appear in the lower right corner of the screen, indicating a Pen or Keyboard response. No response will be accepted until one of these letters appears.

D. Sign On: Each day when you are ready for instruction to begin you must sign on. Simultaneously press the ALTN CODING key (upper left of keyboard) and SPACE BAR (bottom of keyboard). The program will automatically begin.

E. Typed Messages: All responses are light pen except in Block 4. Here you must type some letters as answers to questions. Simply type letters, such as ab or pqr, no capitalization, no spaces, then simultaneously press ALTN CODING key and SPACE BAR.

VII. PAIRING

Some of you are to work together in pairs while the rest will work independently. You will be given a list showing which students work in teams and which work alone.

A. Selecting Partners: Those persons who will work in pairs must choose their partners. Think about the persons you would like to work with for the entire program. On the list indicate your 1st, 2nd, 3rd, 4th, and 5th choice for your partner. Your partner will be assigned as fairly as possible on the basis of this preference. Once partners have been assigned there will be no changing--that is final.

B. Working in Pairs: Those students in the paired group must work together during the entire program. If one member of the team is absent, then the other member can NOT proceed individually. When working as a team, members are encouraged to discuss the problems with each other but not with other teams or individuals. Both members of a pair should agree when making an answer.

APPENDIX C

PREVIEW FRAMES AND CRITERION FRAMES FOR 23 CONCEPT UNITS

CONCEPT UNIT 1

Preview Frame: The Negation of a TAUTOLOGY would result in:

a. a complement
b. a contradiction
c. a tautology
d. a true statement

Criterion Frame: The Negation of a CONTRADICTION would result in:

a. a complement
b. a contradiction
c. a tautology
d. a false statement

CONCEPT UNIT 2

Preview Frame: The set which includes all points not in A is denoted by:

a. $\emptyset$
b. I
c. $\underline{A}$
d. A

Criterion Frame: The set which includes all points in the rectangle is denoted by:

a. $\emptyset$
b. I
c. A
d. $\bar{A}$

CONCEPT UNIT 3

Preview Frame: The switch which is always fixed in the open position is denoted by:

a. $\emptyset$
b. I
c. $\bar{S}$
d. 1

Criterion Frame: The switch which is always fixed in the closed position is denoted by:

a. $\emptyset$
b. I
c. $\bar{S}$
d. 0

CONCEPT UNIT 4

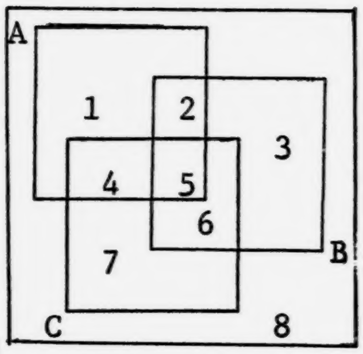
Preview Frame: Let P = Fred is tall, $\bar{P}$ = Fred is short.
Q = Fred is dark, $\bar{Q}$ = Fred is light.
Fred is short and dark is best denoted by:

a. $P \cdot Q$
b. $P \cdot \bar{Q}$
c. $\bar{P} \cdot Q$
d. $\bar{P} \cdot \bar{Q}$

Criterion Frame: Gwin G = Fred is smart.
H = Fred is strong.
Then $\bar{G} \cdot \bar{H}$ is which of the following.

a. Fred is smart and strong.
b. Fred is smart and weak.
c. Fred is dumb and strong.
d. Fred is dumb and weak.

CONCEPT UNIT 5



Preview Frame: Which region in the figure represents the expression $\bar{A} \cdot B \cdot \bar{C}$?

a. region 1
b. region 3
c. region 6
d. region 7

Criterion Frame: Which region in the figure represents the expression $A \cdot \bar{B} \cdot \bar{C}$?

a. region 1
b. region 3
c. region 5
d. region 7

CONCEPT UNIT 6

Preview Frame: If P, Q, and R are electric switches, then which of these expressions has a value of 1 when P = 1, Q = 1, and R = 0?

a. $P \cdot Q \cdot R$
b. $P \cdot Q \cdot \bar{R}$
c. $\bar{P} \cdot \bar{Q} \cdot R$
d. $\bar{P} \cdot \bar{Q} \cdot \bar{R}$

Concept Unit 6 continued.

Criterion Frame: If P, Q, and R are electric switches, then which of these expressions has a value of 1 when P = 0, Q = 0, and R = 1

a. $P \cdot Q \cdot R$
b. $P \cdot Q \cdot \overline{R}$
c. $\overline{P} \cdot \overline{Q} \cdot R$
d. $\overline{P} \cdot \overline{Q} \cdot \overline{R}$

CONCEPT UNIT 7

Preview Frame: If P = Sam is mean. $\overline{P}$ = Sam is nice.
Q = Sam is fast. $\overline{Q}$ = Sam is slow.
Then which statement represents $P + \overline{Q}$?

a. Sam is mean and slow.
b. Sam is mean or slow.
c. Sam is nice and fast.
d. Sam is nice or fast.

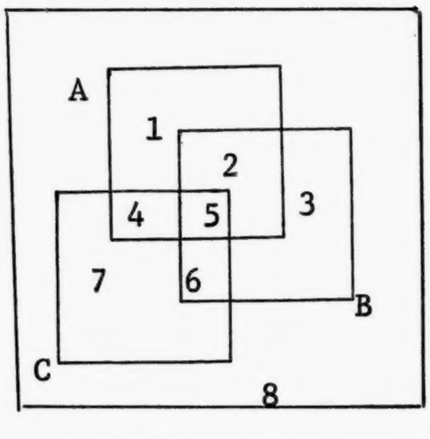
Criterion Frame: If P = Sam is mean. $\overline{P}$ = Sam is nice.
Q = Sam is fast. $\overline{Q}$ = Sam is slow.
Then which statement represents $\overline{P} + Q$?

a. Sam is mean and slow.
b. Sam is mean or slow.
c. Sam is nice and fast.
d. Sam is nice or fast.

CONCEPT UNIT 8

Preview Frame: Let A, B, and C represent the three sets as shown in the figure. Let the eight regions be numbered as shown. Which combination of these regions represents $A + \overline{B} + C$?

a. 2 + 3 + 4 + 5 + 6 + 7 + 8
b. 1 + 2 + 4 + 5 + 6 + 7 + 8
c. 1 + 2 + 3 + 4 + 6 + 7 + 8
d. 1 + 2 + 3 + 4 + 5 + 6 + 8



Criterion Frame: Let A, B, and C be three sets with eight regions as shown. Which combination of these regions represents $\overline{A} + \overline{B} + \overline{C}$?

a. 8
b. 1 + 2 + 3 + 4 + 5 + 6 + 7
c. 1 + 2 + 3 + 4 + 6 + 7 + 8
d. 5

CONCEPT UNIT 9

Preview Frame: $A \cdot (B + \overline{B}) + B \cdot A \cdot \overline{B} + \overline{A} \cdot \overline{A} \cdot \overline{A}$ is equivalent to which of these?

a. A
b. $\overline{A}$
c. 0
d. I

Criterion Frame: $\overline{B} \cdot \overline{B} \cdot \overline{B} + A \cdot B \cdot \overline{A} + (\overline{B} + \overline{B}) \cdot B$ is equivalent to which of these:

a. B
b. $\overline{B}$
c. 0
d. I

CONCEPT UNIT 10

Preview Frame: If R, S, and T are electric switches, such that $R = 1$, $S = 0$, and $T = 0$, then which of these expressions has a value of 0?

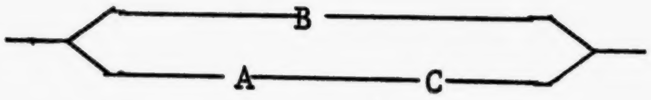
a. $\overline{R} + S + T$
b. $R + \overline{S} + \overline{T}$
c. $\overline{R} + \overline{S} + T$
d. $R + S + T$

Criterion Frame: If R, S, and T are electric switches, such that $R = 1$, $S = 1$, and $T = 0$, then which of these expressions has a value of 0?

a. $R + S + \overline{T}$
b. $R + \overline{S} + T$
c. $\overline{R} + \overline{S} + T$
d. $\overline{R} + \overline{S} + \overline{T}$

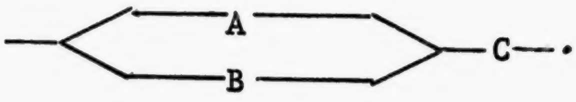
CONCEPT UNIT 11

Preview Frame: Which expression correctly represents the switching network shown?



a. $B \cdot (A \cdot C)$
b. $B + (A + C)$
c. $B \cdot (A + C)$
d. $B + (A \cdot C)$

Criterion Frame: Which expression correctly represents the switching network shown?



a. $A \cdot (B + C)$
b. $A + (B \cdot C)$
c. $C \cdot (A + B)$
d. $C + (A \cdot B)$

CONCEPT UNIT 12

Preview Frame: If M, N, and P are electric switches such that M = 1, N = 0, and P = 0, then which of the following switching networks has a value of 0?

a. $M + N \cdot P$
b. $M + \overline{N} \cdot \overline{P}$
c. $\overline{M} + \overline{N} \cdot \overline{P}$
d. $\overline{M} + N \cdot P$

Criterion Frame: If M, N, and P are electric switches such that M = 0, N = 1, and P = 1, then which of the following switching networks has a value of 0?

a. $M + N \cdot P$
b. $M + \overline{N} \cdot \overline{P}$
c. $\overline{M} + N \cdot P$
d. $\overline{M} + N \cdot P$

CONCEPT UNIT 13

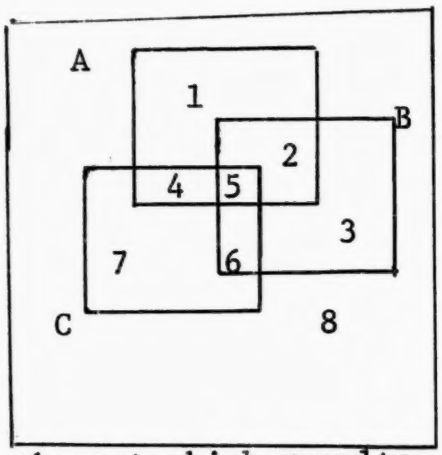
Preview Frame: The expression $A\,(\overline{B} + \emptyset + \overline{\overline{B}}) + \overline{A} \cdot I \cdot B \cdot A + A(B + A + I)$ is equivalent to which of these?

a. A
b. $\overline{A}$
c. I
d. $\emptyset$

Criterion Frame: The expression $\overline{A}(B + A + I) + B \cdot \emptyset \cdot A \cdot I + A(\overline{B} + \emptyset + \overline{\overline{B}})$ is equivalent to which of these?

a. A
b. $\overline{A}$
c. I
d. $\emptyset$

CONCEPT UNIT 14



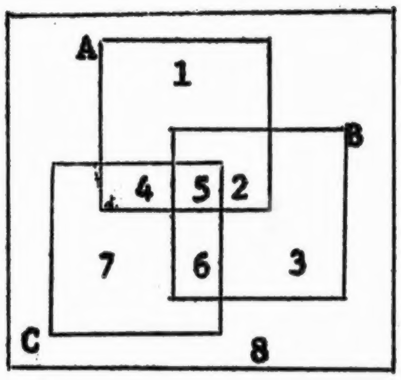
Preview Frame: Which regions in the figure represent the set which results when the NOT operation is applied to the set A + BC?

a. 1 + 2 + 4 + 5
b. 3 + 6 + 7 + 8
c. 1 + 2 + 4 + 5 + 6
d. 3 + 7 + 8

Criterion Frame: Which regions in the figure represent the set which results when the NOT operation is applied to the set B + AC?

a. 2 + 3 + 4 + 5 + 6
b. 1 + 7 + 8
c. 2 + 3 + 5 + 6
d. 1 + 4 + 7 + 8

CONCEPT UNIT 15



Preview Frame: Which regions in the figure represent the set $\overline{\overline{C} + \overline{B \cdot \overline{A}}}$?

a. 2
b. 4
c. 6
d. 8

Criterion Frame: Which regions in the figure represent the set $\overline{\overline{A} + (\overline{\overline{B} \cdot \overline{C}})}$?

a. 1
b. 3
c. 5
d. 7

CONCEPT UNIT 17

Preview Frame: The expression $\overline{\overline{A} \cdot \overline{B} \cdot C + \overline{A}\ \overline{(B + C)}}$ is equivalent to which of these?
a. A + B
c. A + C
d. B + C
e. A + B + C

Criterion Frame: The expression $\overline{\overline{A} \cdot B \cdot \overline{C} + \overline{B}\ \overline{(A + C)}}$ is equivalent to which of these?

a. A + B
b. A + C
c. B + C
d. A + B + C

CONCEPT UNIT 18

Preview Frame: If A and B are electric switches, then $\overline{\overline{A} + \overline{\overline{B}}} = 1$ for which case?
a. A = 1 B = 1
b. A = 1 B = 0
c. A = 0 B = 1
d. A = 0 B = 0

Criterion Frame: If A and B are electric switches, then $\overline{\overline{A} + \overline{\overline{\overline{B}}}} = 1$ for which case?
a. A = 1 B = 1
b. A = 1 B = 0
c. A = 0 B = 1
d. A = 0 B = 0

CONCEPT UNIT 20

Preview Frame: For which case does $\overline{\overline{A} + \overline{\overline{B \cdot C}}} = 1$?

a. A = 1 B = 1 C = 1
b. A = 1 B = 1 C = 0
c. A = 1 B = 0 C = 1
d. A = 1 B = 0 C = 0

Criterion Frame: For which case does $\overline{\overline{\overline{B} \cdot C} + \overline{A}} = 1$?

a. A = 1 B = 1 C = 1
b. A = 1 B = 1 C = 0
c. A = 1 B = 0 C = 1
d. A = 1 B = 0 C = 0

CONCEPT UNIT 29

Preview Frame: Using only the commutative laws, which of these is equivalent to $\overline{P + \overline{Q}\ (\overline{\overline{R} + S} + T)}$?

a. $\overline{P\overline{Q} + (T + \overline{S + R})}$
b. $P + \overline{(T + \overline{S + R})\overline{Q}}$
c. $\overline{(R + \overline{S + T})\ \overline{Q} + P}$
d. $\overline{(T + \overline{S + R})\ P + \overline{Q}}$

Criterion Frame: Using only the commutative laws, which of these is equivalent to $\overline{\overline{P}QR + \overline{KF + G}}$?

a. $\overline{P\overline{QR} + \overline{G + FK}}$

b. $\overline{G + K\ F + \overline{\overline{R\ \overline{P}\ Q}}}$

c. $\overline{P\overline{QR} + \overline{G} + \overline{\overline{KF}}}$

d. $\overline{\overline{G + FK} + R\overline{PQ}}$

CONCEPT UNIT 30

Preview Frame: Using the Associative Laws, which of these is equivalent to $(\overline{A + B}) + K + (X\overline{Y})Z + G$?

a. $\overline{\overline{A + B} + (K + G) + XYZ}$
b. $\overline{\overline{A + (B} + K) + XYZ + G}$
c. $\overline{(\overline{A + B} + K) + (XY)\ (Z + G)}$
d. $\overline{\overline{A + B} + (K + XY)Z + G}$

Concept Unit 30 continued.

Criterion Frame: Using the Associative Laws, which of these is equivalent to $\overline{S(AE + (B + C) + (HD)\ \overline{KC}}$?

a. $\overline{B + C + SEA + HD + \overline{KC}}$
b. $\overline{B + C + AES + DH\overline{CK}}$
c. $\overline{S(AE + B + C) + HD\overline{KC}}$
d. $\overline{S(AEHD) + \overline{KC} + B + C}$

CONCEPT UNIT 31

Preview Frame: Using the AND distributive law, which one of these is equivalent to $(D\overline{AB} + CE + \overline{K})\ \overline{H}M$?

a. $D\overline{AB} + CE + M\overline{HK}$
b. $M\overline{H} + E\ C + \overline{K} + \overline{AB}D$
c. $\overline{H}M(D\overline{AB}) + CE(\overline{H}M) + \overline{K}$
d. $\overline{H}M\overline{K} + MEC\overline{H} + D\overline{H}M\overline{AB}$

Criterion Frame: Using the AND distributive law, which one of these is equivalent to $(P + QZ + \overline{R\overline{V}}W)\ X\overline{Y}$?

a. $(PX)\overline{Y} + \overline{R\overline{V}}WY + QZX\overline{Y}$
b. $PX\overline{Y} + WX\overline{Y}\ \overline{VR} + QZ\overline{Y}Z$
c. $W\overline{RV} + QX\overline{Y}Z + PX\overline{Y}$
d. $P + QZ + \overline{R\overline{V}}WX\overline{Y}$

CONCEPT UNIT 32

Preview Frame: Using the AND distributive law, which of these is equivalent to $AW\overline{P} + AB(V + Y)\ \overline{P}$?

a. $A\ (W\overline{P} + B\overline{P}V + Y)$
b. $\overline{P}\ [\overline{A}W + \overline{P}B(V + W)]$
c. $A\overline{P}\ (W + BV + Y)$
d. $A\overline{P}\ [W + B(V + Y)]$

Criterion Frame: Using the AND distributive law, which of these is equivalent to $GF\overline{K} + (M + R)\ \overline{K}\ \overline{HG}$?

a. $\overline{K}\ [GF + (M + R)\ \overline{H}G]$
b. $G\ [\overline{K}F + (M + R)\ \overline{H}\overline{K}]$
c. $\overline{K}G\ [F + (M + R)\ \overline{H}]$
d. $\overline{K}G\ [F + (M + R)]$

CONCEPT UNIT 33

Preview Frame: The expression $(A + B) 0 + (B + 0) A + A \cdot 0$ is equivalent to which of these?

a. 0
b. A
c. AB
d. $A + B$

Criterion Frame: The expression $(A + 0)B + (B + A) 0 + B \cdot 0$ is equivalent to which of these?

a. 0
b. A
c. AB
d. $A + B$

APPENDIX D

FIVE DAILY QUIZZES FOR 23 CONCEPT UNITS

FIRST QUIZ

1. (Concept Unit 1) A logical statement which is always FALSE is called:
   a. a proposition
   b. a complement
   c. a contradiction
   d. a tautology

2. (Concept Unit 2) The complement of the set which contains all the points in a Venn diagram is equivalent to:
   a. the NULL set
   b. the universal set
   c. the complement set
   d. the JET set

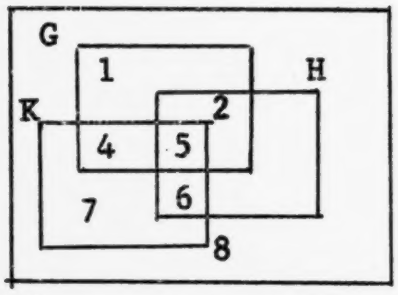
3. (Concept Unit 3) If $\bar{S}$ is a switch which NEVER conducts current, then which of these is equivalent to S?
   a. $\bar{S}$
   b. I
   c. $\emptyset$
   d. 0

SECOND QUIZ

1. (Concept Unit 4) Let P = 5 is an even number.
   Q = 13 is an unlucky number.

   Which of these symbolizes the sentence: "5 is an odd number and 13 is not an unlucky number."
   a. $P \cdot \bar{Q}$
   b. $P + \bar{Q}$
   c. $\bar{P} \cdot \bar{Q}$
   d. $\bar{P} + \bar{Q}$

2. (Concept Unit 5) Given the Venn diagram with sets G, H, and K as shown, which region or regions represent the set K H G?
   a. 4
   b. 7
   c. all but 4
   d. all but 7

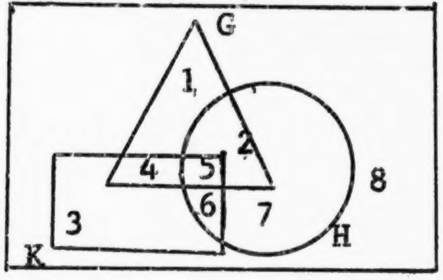


3. (Concept Unit 6) If S and T are electric switches such that S=0 and T=1, then which of these expressions has a value of 0?
   a. $S + T$
   b. $\overline{S \cdot T}$
   c. $\bar{S} \cdot T$
   d. $\overline{\bar{S} \cdot T}$

4. (Concept Unit 7) Let H = Cat is alive.
   K = Cat is not female.
   Which of these symbolizes the sentence: "Cat is Male or alive"?
   a. $H \cdot K$
   b. $H + K$
   c. $H \cdot \bar{K}$
   d. $H + \bar{K}$

Second Quiz continued.

5. (Concept Unit 8) Given the Venn diagram with sets G, H, and K as shown, which region or regions represent the set $(G + \overline{H}) + K$?
   a. 3 + 4 + 5 + 6 + 8
   b. 1 + 2 + 7
   c. 7
   d. all but 7

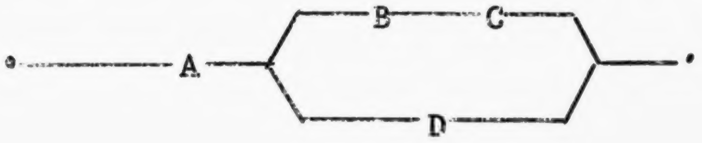


THIRD QUIZ

1. (Concept Unit 9) The expression $C + DC\overline{D} + D(C + \overline{C}) + \overline{C}$ is equivalent to which of these?
   a. C
   b. C + D
   c. ∅
   d. I

2. (Concept Unit 10) If X, Y, and Z are electric switches such that X = 0, Y = 1, and Z = 1, then which of these expressions has a value of 0?
   a. $X + Y + Z$
   b. $\overline{X} + Y + Z$
   c. $X + \overline{Y} + \overline{Z}$
   d. $\overline{X} + \overline{Y} + \overline{Z}$

3. (Concept Unit 11) Which of these is the correct expression for the switching network shown?
   a. A + BC + D
   b. A + (B + C) D
   c. A(BC + D)
   d. A(B + C) D

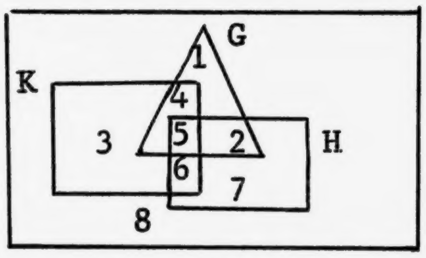


4. (Concept Unit 12) If S, W, and P are electric switches such that S = 1, W = 1, and P = 0, then which network has a value of 1?
   a. $S(\overline{W} + P)$
   b. $\overline{S}(W + P)$
   c. $\overline{S} + WP$
   d. $\overline{S} + W\overline{P}$

5. (Concept Unit 13) The expression $B \cdot I + C \cdot \emptyset \cdot I \cdot A + (B + \overline{\overline{B}})$ is equivalent to which of these?
   a. B
   b. $\overline{B}$
   c. ∅
   d. I

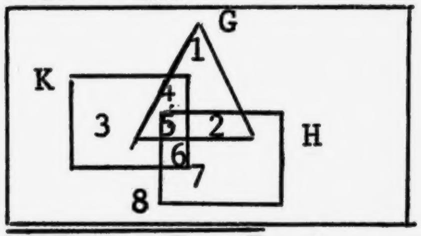
FOURTH QUIZ

1. (Concept Unit 14) Let G, H, and K be three sets with eight regions as shown in the Venn diagram. Which regions represent the set which results when the NOT operation is applied to the set K (G + H)?



a. 4 + 5 + 6
b. 2 + 3 + 4 + 5 + 6
c. 1 + 2 + 3 + 7 + 8
d. 1 + 7 + 8

2. (Concept Unit 15) Let G, H, and K be three sets with eight regions as shown. Which regions represent the set $\overline{GK + \overline{HG}}$?



a. 2
b. all but 2
c. 1 + 2 + 4 + 5 + 6
d. 3 + 7 + 8

3. (Concept Unit 17) The Boolean expression $\overline{\bar{A}\ \bar{B}\ C + \bar{A} + \bar{C}}$ is equivalent to which of these? Draw a Venn diagram if necessary.

a. AB
b. AC
c. BC
d. ABC

4. (Concept Unit 18) If R and S are electric switches, then $\overline{\overline{R\bar{S}} + S} = 1$ for which case?

a. R = 1 and S = 1
b. R = 1 and S = 0
c. R = 0 and S = 1
d. R = 0 and S = 0

5. (Concept Unit 20) For which case does $\overline{\overline{\bar{A}\cdot\bar{B}} + \bar{C}} = 1$?

a. A = 0 B = 1 C = 1
b. A = 0 B = 1 C = 0
c. A = 0 B = 0 C = 1
d. A = 0 B = 0 C = 0

FIFTH QUIZ

1. (Concept Unit 29) Using only the commutative laws, which of these is equivalent to $\overline{P + Q\ (\bar{R} + \bar{S}) + T}$?

a. $\overline{\bar{Q} + P(\bar{S} + R) + T}$
b. $\overline{\bar{Q}\ (\bar{S} + R) + T + P}$
c. $\overline{T + P + R\ (\bar{Q} + \bar{S})}$
d. $\overline{P + \bar{Q}T + (\bar{S} + R)}$

Fifth Quiz continued.

2. (Concept Unit 30) Using only the associative laws, which of these is equivalent to $P(QR)S + (T + V) + (A + B)\ HK$?

   a. $P(QR)\ (S + T + V)\ (A + B)\ (HK)$
   b. $(PQRS) + (T + V + A + B)\ HK$
   c. $PQRS + T + V + (A + B)\ HK$
   d. $PQRS + T + V + A + B + HK$

3. (Concept Unit 31) Using the AND distributive law, which of these is equivalent to $X\overline{Y}\ (P + \overline{QR} + S\overline{VW}) + Z$?

   a. $X\overline{Y}P + Q\overline{R} + S\overline{VW} + Z$
   b. $X\overline{Y}P + X\overline{Y}Q\overline{R} + S\overline{VW} + Z$
   c. $X\overline{Y}P + Q\overline{R}X\overline{Y} + X\overline{Y}S\overline{VW} + X\overline{Y}Z$
   d. $PX\overline{Y} + Q\overline{R}X\overline{Y} + S\overline{VW}X\overline{Y} + Z$

4. (Concept Unit 32) Using the AND distributive law to simplify, which of these is equivalent to $G\overline{A}R + G\overline{A}S\overline{P} + R\overline{A}GE$?

   a. $\overline{A}\ (GR + GS\overline{P}) + RGE$
   b. $G\ (\overline{A}R + \overline{A}S\overline{P}) + R\overline{A}E$
   c. $\overline{A}G\ (R + S\overline{P} + RE)$
   d. $R\overline{A}G\ (S\overline{P} + E)$

5. (Concept Unit 33) The expression $(A + 0)\ B + (B + 0)\ A + (A + B)\ 0$ is equivalent to:

   a. 0
   b. A
   c. AB
   d. $A + B$

APPENDIX E

FINAL EXAMINATION FOR 23 CONCEPT UNITS

Name________________________________

FINAL EXAMINATION: INTRODUCTION TO BOOLEAN ALGEBRA

Directions: Work quickly but carefully. Answer all questions by writing A, B, C, or D in the box to the right of each question. You may work on the scratch paper provided for you. Please answer every question. Good luck!

Answers

1. If Q is a logical statement which is a TAUTOLOGY, then Q would be described as a statement which is

    a. always false
    b. always true
    c. sometimes false and sometimes true
    d. a complement

2. If A is a set of points, then $\overline{A}$ denotes

    a. the set which contains NO points.
    b. the set of points in A.
    c. the set of points NOT in A.
    d. the set of all points in the whole rectangle.

3. If $\overline{S}$ is a switch which will ALWAYS conduct current, then S is equivalent to

    a. I   c. $\overline{S}$
    b. Ø   d. 1

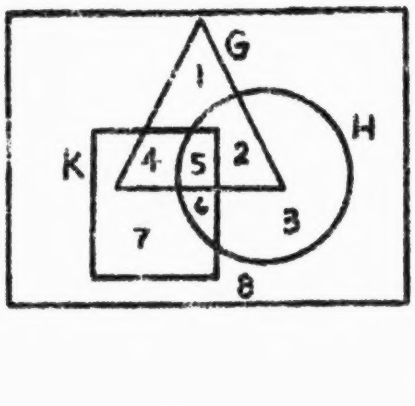
4. Let H = "Cat is alive." and K = "Cat is NOT female.", then the sentence "Cat is female and dead." is denoted:

    a. $\overline{H}\cdot K$ c. $\overline{H}\cdot\overline{K}$

    b. $\overline{H} + K$ d. $\overline{H} + \overline{K}$

5. Given the Venn diagram with three sets G, H, and K and eight regions, then which regions represent the set $\overline{G}\cdot\overline{H}\cdot K$?

    a. 2
    b. 7
    c. all but 2
    d. all but 7



6. If S and T are electric switches such that $S = 0$ and $T = 1$, which of these expressions has a value of 1?

a. $S \cdot T$　　　　c. $S + \overline{T}$

b. $\overline{S \cdot T}$　　　　d. $\overline{S + T}$

---

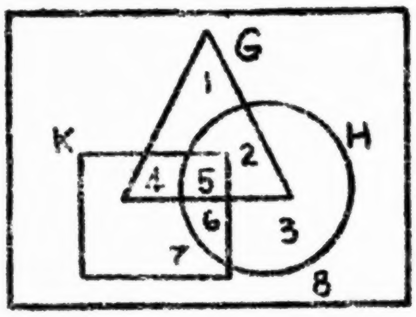
7. Let P = "5 is an even number," and Q = "13 is an unlucky number.", then the statement "13 is an unlucky number or 5 is odd." is denoted

a. $P \cdot \overline{Q}$　　　　c. $P + \overline{Q}$

b. $\overline{P} \cdot Q$　　　　d. $\overline{P} + Q$

---

8. Given the Venn diagram with three sets G, H, and K and eight regions, then which regions represent the set $G + (\overline{H + K})$?



a. 1, 2, 4, 5

b. 1, 2, 4, 5, 8

c. 3, 6, 7, 8

d. 3, 6, 7

---

9. The expression $\overline{C}(D + \overline{D}) + (\overline{C} + \overline{C})C + D\overline{D}$ is equivalent to

a. C　　　　c. ∅

b. $\overline{C}$　　　　d. 1

---

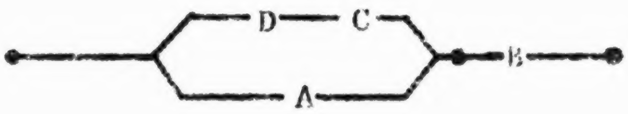
10. If X, Y, and Z are electric switches such that $X = 0$, $Y = 1$, and $Z = 0$, then which of these has a value of 0?

a. $X + Y + Z$　　　　c. $\overline{X} + Y + \overline{Z}$

b. $X + \overline{Y} + Z$　　　　d. $\overline{X} + \overline{Y} + \overline{Z}$

---

11. Which of these is the correct expression for the switching circuit shown?



a. $A + (DC + B)$　　　　c. $B + A(D + C)$

b. $B + (DC + A)$　　　　d. $B(DC + A)$

Answers

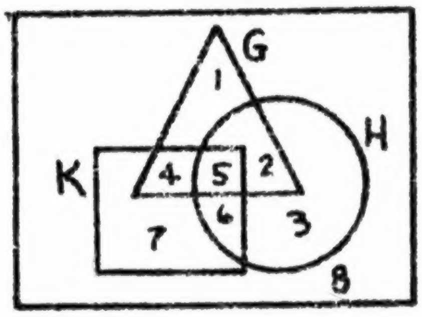
12. If R, S, and W are electric switches such that R = 1, S = 1 and W = 0, then which of these switching networks has a value of 1?

a. $R(S + W)$
c. $\bar{R} + SW$
b. $\bar{R}(S + \bar{W})$
d. $\bar{R} + \overline{SW}$

13. The expression $(A \cdot 1) + (\bar{A} \cdot \emptyset) + (\bar{A} \cdot \bar{A})$ is equivalent to

a. A
c. 1
b. $\bar{A}$
d. $\emptyset$

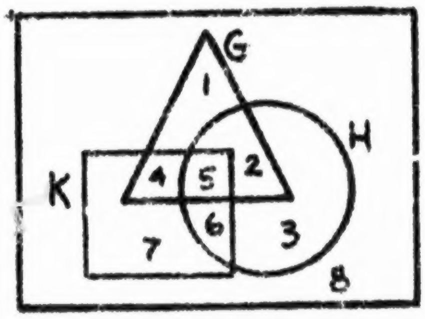
14. Let G, H, and K be three sets with eight regions as shown. Which regions represent the set which results when the NOT operation is applied to the set $G(H + K)$?



a. 2, 4, 5
b. 3, 7, 8
c. 1, 3, 6, 7, 8
d. 1, 2, 4, 5, 6

15. Let G, H, and K be three sets with eight regions as shown. Which regions represent the set

$\overline{\overline{GK} + GH}$?



a. 2
b. all but 2
c. 4
d. all but 4

17. The expression $\overline{\bar{A}B\bar{C} + \bar{B} + \bar{C}}$ is equivalent to which of these? (hint: draw Venn diagram)

a. AB
c. BC
b. AC
d. ABC

18. If R and S are electric switches, then $\overline{R\bar{S} + S} = 1$ for which case?

a. R = 1 and S = 1
c. R = 0 and S = 1
b. R = 1 and S = 0
d. R = 0 and S = 0

Answer.

20. For which case does $\overline{A + \overline{\overline{B}C}} = 1$?

a. A = 0, B = 1, C = 0 c. A = 0, B = 0, C = 1

b. A = 0, B = 1, C = 1 d. A = 0, B = 0, C = 0

---

29. Using only the commutative laws, which of these is equivalent to $\overline{(P + \overline{Q})(\overline{RS} + T)} + W$?

a. $W + \overline{(\overline{SR} + T)(\overline{Q} + P)}$ c. $\overline{(\overline{Q} + P)(\overline{TS} + R) + W}$

b. $\overline{(P + \overline{Q})W + (\overline{RS} + T)}$ d. $\overline{(P + \overline{RS})(\overline{Q} + T) + W}$

---

30. Using only the associative laws, which of these is equivalent to $P + Q + \overline{R} + XY(H + K)$?

a. $(P + Q + \overline{R}) + (XYH + K)$ c. $P + Q + \overline{R} + XYH + K$

b. $P + (Q + \overline{R}) + (XY)(H + K)$ d. $(P + Q + \overline{R} + XY)(H + K)$

---

31. Using the AND distributive law, which of these is equivalent to $\overline{A}B(\overline{X} + \overline{A} + GK) + M$?

a. $\overline{A}B\overline{X} + \overline{A}B + \overline{A}BGK + M$ c. $\overline{A}B\overline{X} + \overline{A} + \overline{A}BGK + M$

b. $\overline{A}B\overline{X} + \overline{A}B\overline{A} + \overline{A}BGK + \overline{A}BM$ d. $\overline{A}B\overline{X} + \overline{A}B\overline{A} + GK + M$

---

32. Using the AND distributive law to simplify, which of these is equivalent to $G\overline{M}V + GT\overline{M}V + V\overline{A}GE$?

a. $G\overline{M}V(T + \overline{A}EM)$ c. $V(G\overline{M} + GT\overline{M}) + \overline{A}GE$

b. $G(\overline{M}V + T\overline{M}V) + V\overline{A}E$ d. $VG(\overline{M} + T\overline{M} + \overline{A}E)$

---

33. The expression $0(C + HK) + (KH + 0) + K(H + G0)$ is equivalent to

a. 0 c. KH

b. K d. K + H

APPENDIX F

ITEM ANALYSIS FOR 23 CONCEPT UNITS

CONCEPT UNIT 1

Preview Frame: The Negation of a TAUTOLOGY would result in:

a. a complement
[✓ b.] a contradiction
c. a tautology
d. a true statement

	Pairs	Individuals	O.T.	U.U. *
a.	6	5		
b.	2	4		
c.	10	7		
d.	0	2		

Criterion Frame: The Negation of a CONTRADICTION would result in:

a. a complement
b. a contradiction
[✓ c.] a tautology
d. a false statement

	Pairs	Individuals	O.T.	U.U.
a.	0	4		
b.	1	1		
c.	11	7		
d.	6	6		

Quiz

1. (Concept Unit 1) A logical statement which is always FALSE is called:

a. a proposition
b. a complement
[✓ c.] a contradiction
d. a tautology

	Pairs	Individuals	O.T.	U.U.
a.	0	0		
b.	2	1		
c.	1	4		
d.	14	13		

Final Exam

1. If Q is a logical statement which is a TAUTOLOGY, then Q would be described as a statement which is

a. always false
[✓ b.] always true
c. sometimes false and sometimes true
d. a complement

	Pairs	Individuals	O.T.	U.U.
a.	7	5		
b.	22	10		
c.	4	1		
d.	3	2		

* O.T.-Overtime; U.U.-Unanticipated Response

CONCEPT UNIT 2

Preview Frame: The set which includes all points not in A is denoted by:

a. Ø
b. I
c. A
d. $\overline{A}$

	Pairs	Individuals	O.T.	U.U.
a.	1	1	0	
b.	1	1	1	
c.	2	2		
d.	14	13		

Criterion Frame: The set which includes all points in the rectangle is denoted by:

a. Ø
b. I
c. A
d. $\overline{A}$

	Pairs	Individuals	O.T.	U.U.
a.	1	1		
b.	11	13		
c.	6	3		
d.	0	1		

2. (Concept Unit 2) The complement of the set which contains all the points in a Venn diagram is equivalent to:

a. the NULL set
b. the universal set
c. the complement set
d. the JET set

	Pairs	Individuals	O.T.	U.U.
a.	5	6	1	
b.	12	9	1	
c.	0	2		
d.	0	0		

2. If A is a set of points, then $\overline{A}$ denotes

a. the set which contains NO points
b. the set of points in A.
c. the set of points NOT in A.
d. the set of all points in the whole rectangle.

	Pairs	Individuals	O.T.	U.U.
a.	6	1		
b.	3	0		
c.	27	17		
d.	0	0		

CONCEPT UNIT 3

Preview Frame: The switch which is always fixed in the open position is denoted by:

[✓ a.] $\emptyset$
b. I
c. $\overline{S}$
d. 1

	Pairs	Individuals	O.T.	U.U.
a.	1	2	0	2
b.	4	3	1	
c.	9	11		
d.	2	1		

Criterion Frame: The switch which is always fixed in the closed position is denoted by:

a. $\emptyset$
[✓ b.] I
c. $\overline{S}$
d. 0

	Pairs	Individuals	O.T.	U.U.
a.	8	11		
b.	3	3		
c.	2	3		
d.	5	1		

3. (Concept Unit 3) If $\overline{S}$ is a switch which NEVER conducts current, then which of these is equivalent to S?

a. $\overline{S}$
[✓ b.] I
c. $\emptyset$
d. 0

	Pairs	Individuals	O.T.	U.U.
a.	0	4		1
b.	8	11		
c.	5	3		
d.	4	0		

3. If $\overline{S}$ is a switch which will ALWAYS conduct current, then S is equivalent to

a. I
[✓ b.] $\emptyset$
c. $\overline{S}$
d. 1

	Pairs	Individuals	O.T.	U.U.
a.	8	1		
b.	25	14		
c.	0	0		
d.	3	3		

CONCEPT UNIT 4

Preview Frame: Let P = Fred is tall, $\bar{P}$ = Fred is short.

Q = Fred is dark, $\bar{Q}$ = Fred is light.

Fred is short and dark is best denoted by:

a. $P \cdot Q$
b. $P \cdot \bar{Q}$
c. $\bar{P} \cdot Q$
d. $\bar{P} \cdot \bar{Q}$

	Pairs	Individuals	O.T.
a.	1	1	0
b.	0	0	1
c.	17	16	
d.	0	0	

Criterion Frame: Gwin G = Fred is smart.
H = Fred is strong.

Then $\bar{G} \cdot \bar{H}$ is which of the following.

a. Fred is smart and strong.
b. Fred is smart and weak.
c. Fred is dumb and strong.
d. Fred is dumb and weak.

	Pairs	Individuals	O.T.
a.	0	1	1
b.	0	2	1
c.	0	0	
d.	17	15	

1. (Concept Unit 4) Let P = 5 is an even number.
Q = 13 is an unlucky number.

Which of these symbolizes the sentence: "5 is an old number and 13 is not an unlucky number."

a. $P \cdot \bar{Q}$
b. $P + \bar{Q}$
c. $\bar{P} \cdot \bar{Q}$
d. $\bar{P} + \bar{Q}$

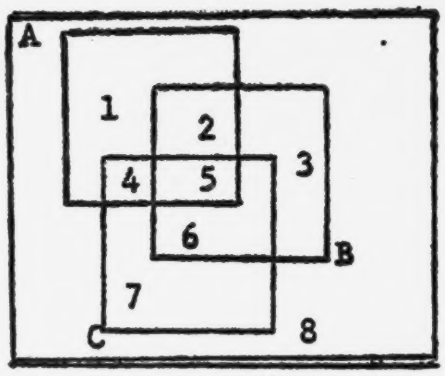
	Pairs	Individuals	O.T.
a.	0	0	1
b.	2	4	1
c.	9	8	
d.	6	5	

4. Let H = "Cat is alive." and K = "Cat is NOT female.", then the sentence "Cat is female and dead." is denoted:

a. $\bar{H} \cdot K$
b. $\bar{H} + K$
c. $\bar{H} \cdot \bar{K}$
d. $\bar{H} + \bar{K}$

	Pairs	Individuals	O.T.
a.	0	0	
b.	2	1	
c.	24	11	
d.	10	6	

CONCEPT UNIT 5



Preview Frame: Which region in the figure represents the expression $\bar{A}\cdot B\cdot\bar{C}$?

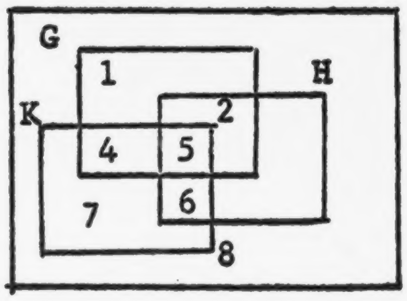
a. region 1
[✓ b.] region 3
c. region 6
d. region 7

	Pairs	Individuals	O.T.
a.	3	2	4
b.	6	12	2
c.	2	1	
d.	3	1	

Criterion Frame: Which region in the figure represents the expression $A\cdot\bar{B}\cdot\bar{C}$?

[✓ a.] region 1
b. region 3
c. region 5
d. region 7

	Pairs	Individuals	O.T.
a.	18	16	1
b.	0	1	
c.	0	1	
d.	0	0	



(Concept Unit 5) Given the Venn diagram with sets G, H, and K as shown, which region or regions represent the set $K\cdot\bar{H}\cdot G$?

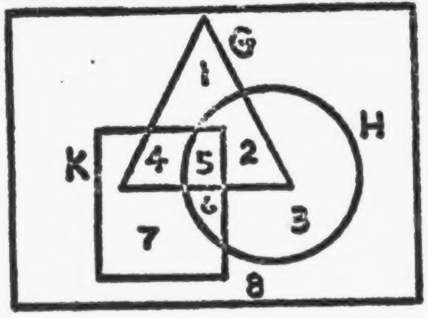
[✓ a.] 4
b. 7
c. all but 4
d. all but 7

	Pairs	Individuals	O.T.
a.	12	5	2
b.	1	1	1
c.	0	3	
d.	3	8	

	Pairs	Individuals	O.T.
a.	2	0	
b.	21	12	
c.	6	2	
d.	6	4	

5. Given the Venn diagram with three sets G, H, and K and eight regions, then which regions represent the set $\bar{G}\cdot\bar{H}\cdot K$?

a. 2
[✓ b.] 7
c. all but 2
d. all but 7



CONCEPT UNIT 6

Preview Frame: If P, Q, and R are electric switches, then which of these expressions has a value of 1 when P = 1, Q = 1, and R = 0?

a. $P\cdot Q\cdot R$
[✓ b.] $P\cdot Q\cdot \bar{R}$
c. $\bar{P}\cdot\bar{Q}\cdot R$
d. $\bar{P}\cdot\bar{Q}\cdot\bar{R}$

	Pairs	Individuals	O.T.	U.U.
a.	4	1		1
b.	13	12		
c.	0	2		
d.	0	3		

Criterion Frame: If P, Q, and R are electric switches, then which of these expressions has a value of 1 when P = 0, Q = 0, and R = 1

a. $P\cdot Q\cdot R$
b. $P\cdot Q\cdot\bar{R}$
[✓ c.] $\bar{P}\cdot\bar{Q}\cdot R$
d. $\bar{P}\cdot\bar{Q}\cdot\bar{R}$

	Pairs	Individuals	O.T.	U.U.
a.	1	0	1	
b.	3	3		
c.	11	15		
d.	2	0		

(Concept Unit 6) If S and T are electric switches such that S=0 and T=1, then which of these expressions has a value of 0?

a. $S + T$
b. $\overline{S\cdot T}$
c. $\bar{S}\cdot T$
[✓ d.] $\overline{\bar{S}\cdot T}$

	Pairs	Individuals	O.T.	U.U.
a.	4	4	0	
b.	2	1	1	
c.	4	3		
d.	8	9		

6. If S and T are electric switches such that S = 0 and T = 1, which of these expressions has a value of 1?

a. $S\cdot T$
[✓ b.] $\overline{S\cdot T}$
c. $S + \bar{T}$
d. $\overline{S + T}$

	Pairs	Individuals	O.T.	U.U.
a.	10	5		
b.	6	7		
c.	3	2		
d.	17	4		

CONCEPT UNIT 7

Preview Frame: If P = Sam is mean. $\bar{P}$ = Sam is nice.
Q = Sam is fast. $\bar{Q}$ = Sam is slow.
Then which statement represents $P + \bar{Q}$?

a. Sam is mean and slow.
[✓ b.] Sam is mean or slow.
c. Sam is nice and fast.
d. Sam is nice or fast.

	Pairs	Individuals	O.T.
a.	5	10	0
b.	13	7	1
c.	0	0	
d.	0	0	

Criterion Frame: If P = Sam is mean. $\bar{P}$ = Sam is nice.
Q = Sam is fast. $\bar{Q}$ = Sam is slow.

Then which statement represents $\bar{P} + Q$?

a. Sam is mean and slow.
b. Sam is mean or slow.
c. Sam is nice and fast.
[✓ d.] Sam is nice or fast.

	Pairs	Individuals	O.T.
a.	0	0	0
b.	0	1	1
c.	4	10	
d.	14	6	

(Concept Unit 7) Let H = Cat is alive.
K = Cat is not female.
Which of these symbolizes the sentence: "Cat is Male or alive"?
a. $H \cdot K$
[✓ b.] $H + K$
c. $H \cdot \bar{K}$
d. $H + \bar{K}$

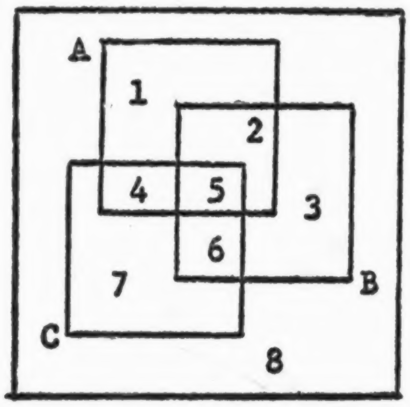
	Pairs	Individuals	O.T.
a.	2	4	
b.	10	5	
c.	1	4	
d.	5	5	

7. Let P = "5 is an even number." and Q = "13 is an unlucky number.", then the statement "13 is an unlucky number or 5 is odd." is denoted

a. $P \cdot \bar{Q}$
b. $\bar{P} \cdot Q$
c. $P + \bar{Q}$
[✓ d.] $\bar{P} + Q$

	Pairs	Individuals	O.T.
a.	1	1	
b.	10	6	
c.	1	0	
d.	24	11	

CONCEPT UNIT 8



Preview Frame: Let A, B, and C represent the three sets as shown in the figure. Let the eight regions be numbered as shown. Which combination of these regions represents $A + \bar{B} + C$?

a. 2 + 3 + 4 + 5 + 6 + 7 + 8
[✓ b.] 1 + 2 + 4 + 5 + 6 + 7 + 8
c. 1 + 2 + 3 + 4 + 6 + 7 + 8
d. 1 + 2 + 3 + 4 + 5 + 6 + 8

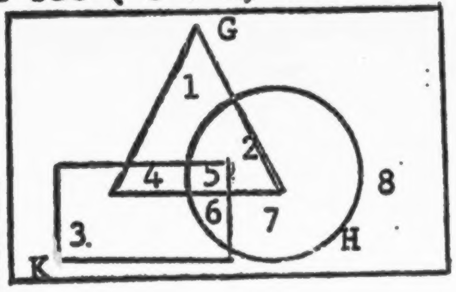
	Pairs	Individuals	O.T.
a.	0	1	5
b.	9	13	3
c.	3	1	
d.	1	0	

Criterion Frame: Let A, B, and C be three sets with eight regions as shown. Which combination of these regions represents $\bar{A} + \bar{B} + \bar{C}$?

a. 8
b. 1 + 2 + 3 + 4 + 5 + 6 + 7
[✓ c.] 1 + 2 + 3 + 4 + 6 + 7 + 8
d. 5

	Pairs	Individuals	O.T.
a.	15	14	0
b.	1	2	1
c.	1	1	
d.	1	0	

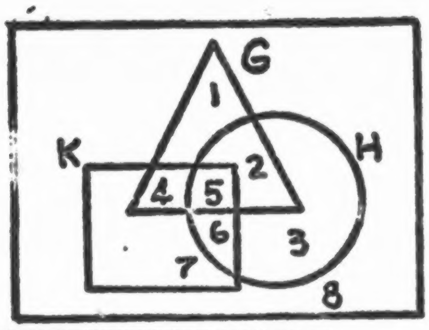
(Concept Unit 8) Given the Venn diagram with sets G, H, and K as shown, which region or regions represent the set $\overline{(G + H)} + K$?



[✓ a.] 3 + 4 + 5 + 6 + 8
b. 1 + 2 + 7
c. 7
d. all but 7

	Pairs	Individuals	O.T.
a.	13	14	1
b.	2	2	
c.	1	0	
d.	1	2	

8. Given the Venn diagram with three sets G, H, and K and eight regions, then which regions represent the set $G + \overline{(H + K)}$?



a. 1, 2, 4, 5
[✓ b.] 1, 2, 4, 5, 8
c. 3, 6, 7, 8
d. 3, 6, 7

	Pairs	Individuals	O.T.
a.	19	5	
b.	14	11	
c.	1	2	
d.	2	0	

CONCEPT UNIT 9

Preview Frame: $A \cdot (B + \overline{B}) + B \cdot A \cdot \overline{B} + \overline{A} \cdot \overline{A} \cdot \overline{A}$ is equivalent to which of these?

a. A
b. $\overline{A}$
c. 0
[✓ d.] I

	Pairs	Individuals	O.T.	U.U.
a.	2	1	4	
b.	6	1	5	
c.	1	10		
d.	5	0		

Criterion Frame: $\overline{B} \cdot \overline{B} \cdot \overline{B} + A \cdot B \cdot \overline{A} + (\overline{B} + \overline{B}) \cdot B$ is equivalent to which of these?

a. B
[✓ b.] $\overline{B}$
c. 0
d. I

	Pairs	Individuals	O.T.	U.U.
a.	2	3	6	1
b.	3	5	3	1
c.	2	3		
d.	4	2		

(Concept Unit 9) The expression $C + DC\overline{\overline{D}} + D(C + \overline{C}) + \overline{C}$ is equivalent to which of these?

a. C
b. $C + D$
c. 0
[✓ d.] I

	Pairs	Individuals	O.T.	U.U.
a.	1	7	4	1
b.	7	5	3	
c.	2	5		
d.	6	2		

9. The expression $\overline{C}(D + \overline{D}) + (\overline{C} + \overline{C})C + D\overline{D}$ is equivalent to

a. C
[✓ b.] $\overline{C}$
c. 0
d. I

	Pairs	Individuals	O.T.	U.U.
a.	1	1		
b.	17	5		
c.	11	9		
d.	7	2		

CONCEPT UNIT 10

Preview Frame: If R, S, and T are electric switches, such that R = 1, S = 0, and T = 0, then which of these expressions has a value of 0?

[✓ a] $\bar{R} + S + T$
b. $R + \bar{S} + \bar{T}$
c. $\bar{R} + \bar{S} + T$
d. $R + S + T$

	Pairs	Individuals	O.T.	U.U.
a.	16	14	0	
b.	2	0	1	
c.	0	0		
d.	0	2		

Criterion Frame: If R, S, and T are electric switches, such that R = 1, S = 1, and T = 0, then which of these expressions has a value of 0?

a. $R + S + \bar{T}$
b. $R + \bar{S} + \bar{T}$
[✓ c] $\bar{R} + \bar{S} + T$
d. $\bar{R} + \bar{S} + \bar{T}$

	Pairs	Individuals	O.T.	U.U.
a.	2	1		
b.	0	1		
c.	16	15		
d.	0	0		

(Concept Unit 10) If X, Y, and Z are electric switches such that X = 0, Y = 1, and Z = 1, then which of these expressions has a value of 0?

. $X + Y + Z$
b. $\bar{X} + Y + Z$
[✓ c] $X + \bar{Y} + \bar{Z}$
d. $\bar{X} + \bar{Y} + \bar{Z}$

	Pairs	Individuals	O.T.	U.U.
a.	0	0		
b.	3	1		
c.	15	17		
d.	0	0		

10. If X, Y, and Z are electric switches such that X = 0, Y = 1, and Z = 0, then which of these has a value of 0?

a. $X + Y + Z$ c. $\bar{X} + Y + \bar{Z}$

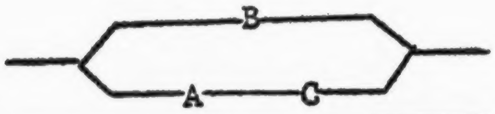
[✓ b] $X + \bar{Y} + Z$ d. $\bar{X} + \bar{Y} + \bar{Z}$

	Pairs	Individuals	O.T.	U.U.
a.	1	0		
b.	34	17		
c.	1	1		
d.	0	0		

CONCEPT UNIT 11

Preview Frame: Which expression correctly represents the switching network shown?

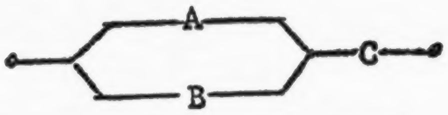
a. B • (A • C)
b. B + (A + C)
c. B • (A + C)
[✓ d.] B + (A • C)



	Pairs	Individuals	O.T.	U.U.
a.	4	0		
b.	6	5		
c.	4	8		
d.	4	4		

Criterion Frame: Which expression correctly represents the switching network shown?

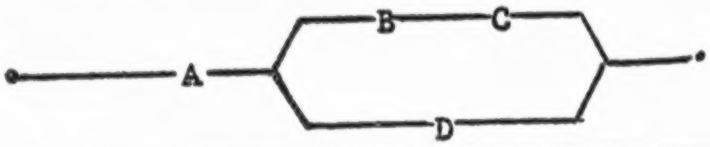
a. A • (B + C)
b. A + (B•C)
[✓ c.] C • (A + B)
d. C + (A•B)



	Pairs	Individuals	O.T.	U.U.
a.	0	2		
b.	0	0		
c.	12	13		
d.	6	3		

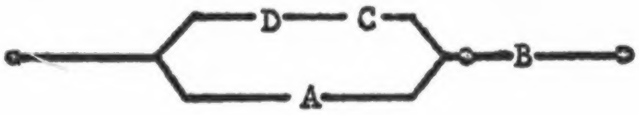
(Concept Unit 11) Which of these is the correct expression for the switching network shown?

a. A + BC + D
b. A + (B + C) D
[✓ c.] A(BC + D)
d. A(B + C) D



	Pairs	Individuals	O.T.	U.U.
a.	3	5	1	
b.	4	2		
c.	5	9		
d.	5	2		

11. Which of these is the correct expression for the switching circuit shown?



a. A + (DC + B)
b. B + (DC + A)
c. B + A(D + C)
[✓ d.] B(DC + A)

	Pairs	Individuals	O.T.	U.U.
a.	3	3		
b.	13	4		
c.	3	1		
d.	17	10		

CONCEPT UNIT 12

Preview Frame: If M, N, and P are electric switches such that M = 1, N = 0, and P = 0, then which of the following switching networks has a value of 0?

a. $M + N \cdot P$
b. $M + \overline{N} \cdot \overline{P}$
c. $\overline{M} + \overline{N} \cdot \overline{P}$
[✓ d.] $\overline{M} + N \cdot P$

	Pairs	Individuals	O.T.	U.U.
a.	1	1	0	
b.	0	0	1	
c.	2	1		
d.	15	14		

Criterion Frame: If M, N, and P are electric switches such that M = 0, N = 1, and P = 1, then which of the following switching networks has a value of 0?

a. $M + N \cdot P$
[✓ b.] $M + \overline{N} \cdot \overline{P}$
c. $\overline{M} + N \cdot P$
d. $\overline{M} + N \cdot P$

	Pairs	Individuals	O.T.	U.U.
a.	0	0		
b.	17	15		
c.	1	1		
d.	0	1		

(Concept Unit 12) If S, W, and P are electric switches such that S = 1, W = 1, and P = 0, then which network has a value of 1?

a. $S\ (\overline{W} + P)$
b. $\overline{S}\ (W + P)$
c. $\overline{S} + WP$
[✓ d.] $\overline{S} + W\overline{P}$

	Pairs	Individuals	O.T.	U.U.
a.	6	7	2	
b.	1	1	3	
c.	4	2		
d.	5	5		

12. If R, S, and W are electric switches such that R = 1, S = 1 and W = 0, then which of these switching networks has a value of 1?

[✓ a.] $R(S + W)$
b. $\overline{R}(S + \overline{W})$
c. $\overline{R} + SW$
d. $\overline{R} + \overline{S}W$

	Pairs	Individuals	O.T.	U.U.
a.	25	11		
b.	3	4		
c.	3	3		
d.	4	0		

CONCEPT UNIT 13

Preview Frame: The expression A (B + Ø + B) + A I·B·A + A(B + A + I) is equivalent to which of these?

a. A
b. A
c. I
d. Ø

	Pairs	Individuals	O.T.	U.U.
a.	4	1	2	
b.	3	5	2	
c.	5	3		
d.	3	6		

Criterion Frame: The expression A(B + A + I) + B·Ø·A·I + A(B + Ø + B) is equivalent to which of these?

a. A
b. A
c. I
d. Ø

	Pairs	Individuals	O.T.	U.U.
a.	3	1	4	
b.	2	5	2	
c.	4	5		
d.	5	4		

(Concept Unit 13) The expression B·I + C·Ø·I A + (B + B) is equivalent to which of these?

a. B
b. B
c. Ø
d. I

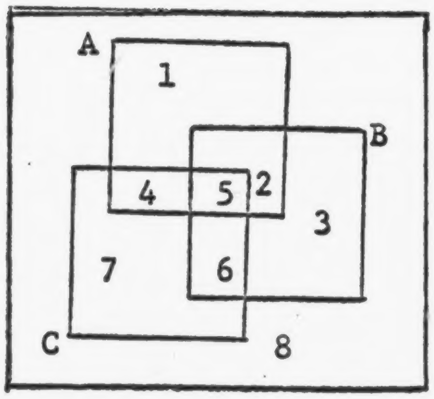
	Pairs	Individuals	O.T.	U.U.
a.	2	1	1	2
b.	3	5		
c.	5	6		
d.	5	6		

13. The expression (A·I) + (A Ø) + (A A) is equivalent to

a. A
b. A
c. I
d. Ø

	Pairs	Individuals	O.T.	U.U.
a.	4	3		
b.	15	5		
c.	9	5		
d.	8	5		

CONCEPT UNIT 14



Preview Frame: Which regions in the figure represent the set which results when the NOT operation is applied to the set A + BC?

a. 1 + 2 + 4 + 5
b. 3 + 6 + 7 + 8
c. 1 + 2 + 4 + 5 + 6
[✓ d.] 3 + 7 + 8

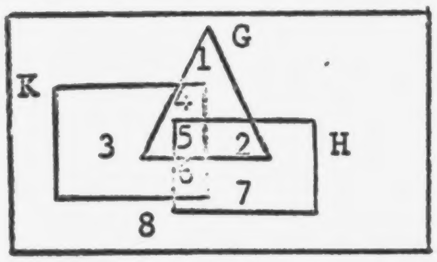
	Pairs	Individuals	O.T.
a.	2	2	8
b.	1	2	5
c.	3	5	
d.	4	4	

Criterion Frame: Which regions in the figure represent the set which results when the NOT operation is applied to the set B + AC?

a. 2 + 3 + 4 + 5 + 6
[✓ b.] 1 + 7 + 8
c. 2 + 3 + 5 + 6
d. 1 + 4 + 7 + 8

	Pairs	Individuals	O.T.
a.	1	3	2
b.	11	6	5
c.	0	1	
d.	2	3	

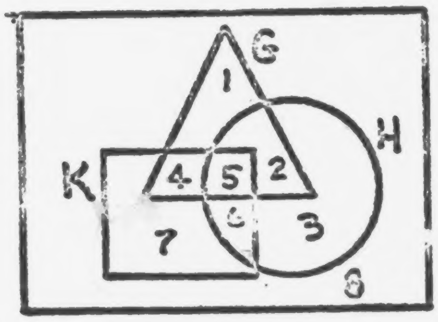
(Concept Unit 14) Let G, H, and K be three sets with eight regions as shown in the Venn diagram. Which regions represent the set which results when the NOT operation is applied to the set K (G + H)?



a. 4 + 5 + 6
b. 2 + 3 + 4 + 5 + 6
[✓ c.] 1 + 2 + 3 + 7 + 8
d. 1 + 7 + 8

	Pairs	Individuals	O.T.
a.	2	4	3
b.	3	3	5
c.	5	5	
d.	4	1	

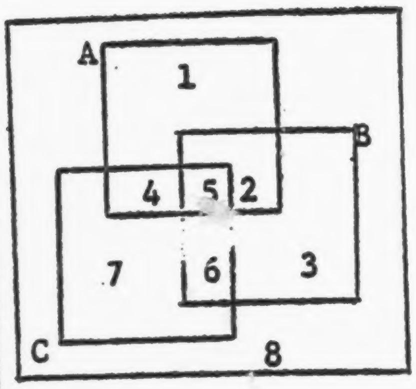
14. Let G, H, and K be three sets with eight regions as shown. Which regions represent the set which results when the NOT operation is applied to the set G(H + K) ?



a. 2, 4, 5
b. 3, 7, 8
[✓ c.] 1, 3, 6, 7, 8
d. 1, 2, 4, 5, 6

	Pairs	Individuals	O.T.
a.	10	2	
b.	10	6	
c.	11	9	
d.	4	1	

CONCEPT UNIT 15



Preview Frame: Which regions in the figure represent the set $\overline{\overline{C} + \overline{B \cdot \overline{A}}}$?

a. 2
b. 4
[✓ c.] 6
d. 8

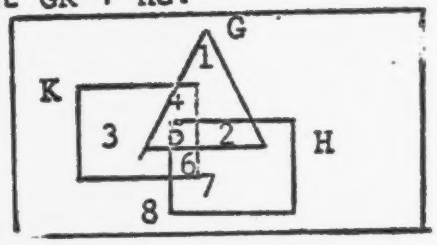
	Pairs	Individuals	O.T.
a.	2	3	7
b.	2	1	6
c.	3	3	
d.	4	5	

Criterion Frame: Which regions in the figure represent the set $\overline{\overline{A} + (\overline{\overline{B} \cdot \overline{C}})}$?

[✓ a.] 1
b. 3
c. 5
d. 7

	Pairs	Individuals	O.T.
a.	11	11	1
b.	1	5	0
c.	3	2	
d.	2	0	

(Concept Unit 15) Let G, H, and K be three sets with eight regions as shown. Which regions represent the set $\overline{GK + \overline{HG}}$?

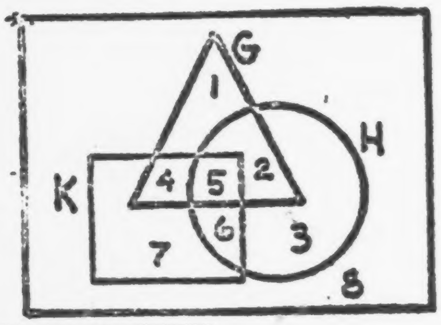


[✓ a.] 2
b. all but 2
c. 1 + 2 + 4 + 5 + 6
d. 3 + 7 + 8

	Pairs	Individuals	O.T.
a.	2	3	5
b.	3	3	5
c.	5	4	
d.	3	3	

15. Let G, H, and K be three sets with eight regions as shown. Which regions represent the set

$\overline{\overline{GK} + GH}$?



a. 2
b. all but 2
[✓ c.] 4
d. all but 4

	Pairs	Individuals	O.T.
a.	1	3	
b.	15	3	
c.	17	8	
d.	3	4	

CONCEPT UNIT 17

Preview Frame: The expression $\overline{\overline{A}\cdot\overline{B}\cdot C + \overline{A}\ (\overline{B + C})}$ is equivalent to which of these?

[✓ a.] A + B
b. A + C
d. B + C
e. A + B + C

	Pairs	Individuals	O.T.
a.	1	8	7
b.	3	3	1
c.	4	1	
d.	3	5	

Criterion Frame: The expression $\overline{\overline{A}\cdot B\cdot\overline{C} + \overline{B}\ (\overline{A + C})}$ is equivalent to which of these?

a. A + B
[✓ b.] A + C
c. B + C
d. A + B + C

	Pairs	Individuals	O.T.
a.	1	0	3
b.	8	8	2
c.	0	5	
d.	6	3	

(Concept Unit 17) The Boolean expression $\overline{\overline{A}\cdot\overline{B}\cdot C + \overline{A} + \overline{C}}$ is equivalent to which of these? Draw a Venn diagram if necessary.

a. AB
[✓ b.] AC
c. BC
d. ABC

	Pairs	Individuals	O.T.
a.	7	6	3
b.	5	4	3
c.	1	3	
d.	2	2	

17. The expression $\overline{\overline{A}B\overline{C} + \overline{B} + \overline{C}}$ is equivalent to which of these? (hint: draw Venn diagram)

a. AB
b. AC
[✓ c.] BC
d. ABC

	Pairs	Individuals	O.T.
a.	2	3	
b.	18	6	
c.	4	4	
d.	12	5	

CONCEPT UNIT 18

Preview Frame: If A and B are electric switches, then $\overline{\overline{A} + \overline{\overline{\overline{B}}}} = 1$ for which case?

a. A = 1 B = 1
[✓ b.] A = 1 B = 0
c. A = 0 B = 1
d. A = 0 B = 0

	Pairs	Individuals	O.T.
a.	3	6	3
b.	8	6	2
c.	3	2	
d.	1	2	

Criterion Frame: If A and B are electric switches, then $\overline{\overline{A} + \overline{\overline{\overline{B}}}} = 1$ for which case?

[✓ a.] A = 1 B = 1
b. A = 1 B = 0
c. A = 0 B = 1
d. A = 0 B = 0

	Pairs	Individuals	O.T.
a.	4	7	3
b.	4	3	2
c.	6	3	
d.	1	3	

(Concept Unit 18) If R and S are electric switches, then $\overline{\overline{R\overline{S}} + S} = 1$ for which case?

a. R = 1 and S = 1
[✓ b.] R = 1 and S = 0
c. R = 0 and S = 1
d. R = 0 and S = 0

	Pairs	Individuals	O.T.
a.	4	2	2
b.	1	4	2
c.	8	6	
d.	3	4	

18. If R and S are electric switches, then $\overline{R\overline{S}} + S = 1$ for which case?

a. R = 1 and S = 1
c. R = 0 and S = 1
b. R = 1 and S = 0
[✓ d.] R = 0 and S = 0

	Pairs	Individuals	O.T.
a.	9	5	
b.	7	6	
c.	12	4	
d.	8	3	

CONCEPT UNIT 20

Preview Frame: For which case does $\overline{\bar{A} + \overline{B \cdot \bar{C}}} = 1$?

a. A = 1 B = 1 C = 1
[✓ b.] A = 1 B = 1 C = 0
c. A = 1 B = 0 C = 1
d. A = 1 B = 0 C = 0

	Pairs	Individuals	O.T.
a.	1	0	
b.	12	12	
c.	5	3	
d.	0	3	

Criterion Frame: For which case does $\overline{\overline{\bar{B} \cdot C} + \bar{A}} = 1$?

a. A = 1 B = 1 C = 1
b. A = 1 B = 1 C = 0
[✓ c.] A = 1 B = 0 C = 1
d. A = 1 B = 0 C = 0

	Pairs	Individuals	O.T.
a.	0	2	2
b.	4	2	1
c.	13	9	
d.	0	4	

(Concept Unit 20) For which case does $\overline{\overline{\bar{A} \cdot \bar{B}} + \bar{C}} = 1$?

a. A = 0 B = 1 C = 1
b. A = 0 B = 1 C = 0
[✓ c.] A = 0 B = 0 C = 1
d. A = 0 B = 0 C = 0

	Pairs	Individuals	O.T.
a.	1	1	1
b.	4	4	
c.	11	12	
d.	1	1	

20. For which case does $\overline{A + \overline{\bar{B}C}} = 1$?

a. A = 0, B = 1, C = 0
b. A = 0, B = 1, C = 1
[✓ c.] A = 0, B = 0, C = 1
d. A = 0, B = 0, C = 0

	Pairs	Individuals	O.T.
a.	6	2	
b.	2	3	
c.	26	11	
d.	2	2	

CONCEPT UNIT 29

Preview Frame: Using only the commutative laws, which of these is equivalent to $\overline{P + \overline{Q}\,(\overline{R + S} + T)}$?

a. $\overline{P\overline{Q} + (T + \overline{S + R})}$
[✓ b.] $P + \overline{(T + \overline{S + R})\overline{Q}}$
c. $\overline{(R + \overline{S + T})\,\overline{Q} + P}$
d. $\overline{(T + \overline{S + R})\,P + \overline{Q}}$

	Pairs	Individuals	O.T.
a.	6	3	3
b.	2	5	3
c.	2	3	
d.	5	4	

Criterion Frame: Using only the commutative laws, which of these is equivalent to $\overline{\overline{PQ}R + \overline{KF + G}}$?

a. $\overline{P\overline{QR} + \overline{G + FK}}$
b. $\overline{G + KF + \overline{R\,\overline{PQ}}}$
c. $\overline{P\overline{QR} + \overline{G} + \overline{KF}}$
[✓ d.] $\overline{\overline{G + FK} + R\overline{PQ}}$

	Pairs	Individuals	O.T.
a.	0	4	
b.	3	1	
c.	1	2	
d.	14	11	

(Concept Unit 29) Using only the commutative laws, which of these is equivalent to $\overline{P + Q\,(\overline{R} + \overline{S}) + T}$?

a. $\overline{\overline{Q} + P(\overline{S} + R) + T}$
[✓ b.] $\overline{\overline{Q}\,(\overline{S} + R) + T + P}$
c. $\overline{T + P + R\,(\overline{Q} + \overline{S})}$
d. $\overline{P + \overline{Q}T + (\overline{S} + R)}$

	Pairs	Individuals	O.T.
a.	14	8	1
b.	2	4	1
c.	1	1	
d.	0	4	

29. Using only the commutative laws, which of these is equivalent to $\overline{(P + \overline{Q})(\overline{RS} + T) + W}$?

[✓ a.] $\overline{W + (\overline{SR} + T)(\overline{Q} + P)}$
b. $\overline{(P + \overline{Q})W + (\overline{RS} + T)}$
c. $\overline{(\overline{Q} + P)(\overline{TS} + R) + W}$
d. $\overline{(P + \overline{RS})(\overline{Q} + T) + W}$

	Pairs	Individuals	O.T.
a.	26	12	
b.	5	2	
c.	2	1	
d.	3	3	

CONCEPT UNIT 30

Preview Frame: Using the Associative Laws, which of these is equivalent to $(\overline{A + B}) + K + (XY)Z + G$?

[✓ a] $\overline{\overline{A + B} + (K + G) + XYZ}$

b. $\overline{\overline{A + (B} + K) + XYZ + G}$

c. $\overline{(\overline{A + B} + K) + (XY)\ (Z + G)}$

d. $\overline{\overline{A + B} + (K + XY)Z + G}$

	Pairs	Individuals	O.T.
a.	7	1	1
b.	3	6	6
c.	4	3	
d.	2	2	

Criterion Frame: Using the Associative Laws, which of these is equivalent to $\overline{S(AE) + (B + C) + (HD)\ \overline{KC}}$?

a. $\overline{B + C + SEA + HD + \overline{KC}}$

[✓ b] $\overline{B + C + AES + DH\overline{CK}}$

c. $\overline{S(AE + B + C) + HD\overline{KC}}$

d. $\overline{S(AEHD) + \overline{KC} + B + C}$

	Pairs	Individuals	O.T.
a.	10	12	
b.	3	1	
c.	3	2	
d.	2	3	

(Concept Unit 30) Using only the associative laws, which of these is equivalent to P(QR)S + (T + V) + (A + B) HK?

a. P(QR) (S + T + V) (A + B) (HK)
b. (PQRS) + (T + V + A + B) HK
[✓ c] PQRS + T + V + (A + B) HK
d. PQRS + T + V + A + B + HK

	Pairs	Individuals	O.T.
a.	3	4	0
b.	7	3	2
c.	5	5	
d.	3	4	

30. Using only the associative laws, which of these is equivalent to $P + Q + \overline{R} + XY(H + K)$?

a. $(P + Q + \overline{R}) + (XYH + K)$ c. $P + Q + \overline{R} + XYH + K$

[✓ b] $P + (Q + \overline{R}) + (XY)(H + K)$ d. $(P + Q + \overline{R} + XY)(H + K)$

	Pairs	Individuals	O.T.
a.	6	2	
b.	19	9	
c.	3	3	
d.	7	4	

CONCEPT UNIT 31

Preview Frame: Using the AND distributive law, which one of these is equivalent to $(D\overline{A}\overline{B} + CE + \overline{K})\ \overline{H}M$?

a. $D\overline{A}\overline{B} + CE + M\overline{H}\overline{K}$

b. $M\overline{H} + EC + \overline{K} + \overline{A}\overline{B}D$

c. $\overline{H}M(D\overline{A}\overline{B}) + CE(\overline{H}M) + \overline{K}$

[✓ d] $\overline{H}M\overline{K} + MEC\overline{H} + D\overline{H}M\overline{A}\overline{B}$

	Pairs	Individuals	O.T.
a.	6	7	1
b.	3	4	1
c.	5	3	
d.	3	3	

Criterion Frame: Using the AND distributive law, which one of these is equivalent to $(P + QZ + \overline{R}\overline{V}W)\ X\overline{Y}$?

a. $(PX)\overline{Y} + \overline{R}\overline{V}WY + QZX\overline{Y}$

[✓ b] $PX\overline{Y} + WX\overline{Y}\overline{V}\overline{R} + QZ\overline{Y}Z$

c. $W\overline{R}\overline{V} + QX\overline{Y}Z + PX\overline{Y}$

d. $P + QZ + \overline{R}\overline{V}WX\overline{Y}$

	Pairs	Individuals	O.T.
a.	1	2	2
b.	6	8	0
c.	4	1	
d.	5	7	

(Concept Unit 31) Using the AND distributive law, which of these is equivalent to $X\overline{Y}\ (P + Q\overline{R} + S\overline{V}\overline{W}) + Z$?

a. $X\overline{Y}P + Q\overline{R} + S\overline{V}\overline{W} + Z$

b. $X\overline{Y}P + X\overline{Y}Q\overline{R} + S\overline{V}\overline{W} + Z$

c. $X\overline{Y}P + Q\overline{R}X\overline{Y} + X\overline{Y}S\overline{V}\overline{W} + X\overline{Y}Z$

[✓ d] $PX\overline{Y} + Q\overline{R}X\overline{Y} + S\overline{V}\overline{W}X\overline{Y} + Z$

	Pairs	Individuals	O.T.
a.	8	7	3
b.	2	2	1
c.	4	7	
d.	2	1	

31. Using the AND distributive law, which of these is equivalent to $\overline{A}B(\overline{X} + \overline{A} + GK) + M$?

[✓ a] $\overline{A}B\overline{X} + \overline{A}B + \overline{A}BGK + M$

b. $\overline{A}B\overline{X} + \overline{A}B\overline{A} + \overline{A}BGK + \overline{A}BM$

c. $\overline{A}B\overline{X} + \overline{A} + \overline{A}BGK + M$

d. $\overline{A}B\overline{X} + \overline{A}B\overline{A} + GK + M$

	Pairs	Individuals	O.T.
a.	7	7	
b.	18	10	
c.	4	0	
d.	7	1	

CONCEPT UNIT 32

Preview Frame: Using the AND distributive law, which of these is equivalent to $AW\bar{P} + AB(V + Y)\ \bar{P}$?

a. $A\ (W\bar{P} + B\bar{P}V + Y)$

b. $\bar{P}\ [AW + \bar{P}B(V + W)]$

c. $A\bar{P}\ (W + BV + Y)$

[✓ d.] $A\bar{P}\ [W + B\ (V + Y)]$

	Pairs	Individuals	O.T.
a.	4	2	1
b.	7	7	1
c.	5	7	
d.	2	1	

Criterion Frame: Using the AND distributive law, which of these is equivalent to $GF\bar{\bar{K}} + (M + R)\ \bar{K}\ \bar{H}\bar{G}$?

[✓ a.] $\bar{K}\ [\bar{G}F + (M + R)\ \bar{H}G]$

b. $G\ [\bar{K}F + (M + R)\ \bar{H}\bar{K}]$

c. $\bar{K}G\ [F + (M + R)\ \bar{H}]$

d. $\bar{\bar{K}}G\ [F + (M + R)]$

	Pairs	Individuals	O.T.
a.	5	6	3
b.	4	6	2
c.	7	3	
d.	0	1	

(Concept Unit 32) Using the AND distributive law to simplify, which of these is equivaltne to $G\bar{A}R + G\bar{A}S\bar{P} + R\bar{A}GE$?

a. $\bar{A}\ (GR + GS\bar{P}) + RGE$

b. $G\ (\bar{A}R + \bar{A}S\bar{P}) + R\bar{A}E$

[✓ c.] $\bar{A}G\ (R + S\bar{P} + RE)$

d. $R\bar{A}G\ (S\bar{P} + E)$

	Pairs	Individuals	O.T.	U.U.
a.	4	5	2	
b.	4	4	0	
c.	6	5		
d.	2	4		

32. Using the AND distributive law to simplify, which of these is equivalent to $G\bar{M}V + GT\bar{M}V + V\bar{A}GE$?

a. $G\bar{M}V(T + \bar{A}EM)$

b. $G(\bar{M}V + T\bar{M}V) + V\bar{A}E$

c. $V(G\bar{M} + GT\bar{M}) + \bar{A}GE$

[✓ d.] $VG(\bar{M} + T\bar{M} + \bar{A}E)$

	Pairs	Individuals	O.T.	U.U.
a.	1	3		
b.	5	0		
c.	8	6		
d.	22	9		

CONCEPT UNIT 33

Preview Frame: The expression $(A + B) 0 + (B + 0) A + A \cdot 0$ is equivalent to which of these?

a. 0
b. A
[✓ c.] AB
d. $A + B$

	Pairs	Individuals	O.T.	U.U.
a.	15	10	1	
b.	0	0	2	
c.	2	1		
d.	0	5		

Criterion Frame: The expression $(A + 0) B + (B + A) 0 + B \cdot 0$ is equivalent to which of these?

a. 0
b. A
[✓ c.] AB
d. $A + B$

	Pairs	Individuals	O.T.	U.U
a.	6	8		0
b.	0	1		2
c.	6	5		
d.	6	2		

(Concept Unit 33) The expression $(A + 0) B + (B + 0) A + (A + B) 0$ is equivalent to:

a. 0
b. A
[✓ c.] AB
d. $A + B$

	Pairs	Individuals	O.T.	U.U.
a.	3	4	2	
b.	0	3	3	
c.	10	4		
d.	4	4		

33. The expression $0(G + HK) + (KH + 0) + K(H + G0)$ is equivalent to

a. 0
b. K
[✓ c.] KH
d. $K + H$

	Pairs	Individuals	O.T.	U.U
a.	18	7		
b.	0	1		
c.	16	9		
d.	2	1		

APPENDIX G

QUESTIONNAIRE FOR BOOLEAN ALGEBRA EXPERIMENT

Name______________________________

QUESTIONNAIRE FOR BOOLEAN ALGEBRA EXPERIMENT:

1. Your personal reaction toward using computers for instruction is-

    a. you enjoyed it very much
    b. you felt it was O.K.
    c. you didn't particularly enjoy it
    d. you definitely disliked it

2. While taking the program, the computer made you feel-

    a. very relaxed and at ease
    b. moderately relaxed
    c. somewhat tense
    d. very tense and not at ease

3. When taking the lessons, you felt-

    a. you had to work slower than you wanted to
    b. you worked at the right speed
    c. you had to work faster than you wanted to

4. If you had a choice as to how the material would be presented, you would choose-

    a. a good teacher
    b. a good textbook
    c. a computer presentation
    d. other (please specify)______________________

5. The most undesirable factor of the computer was-

    a. There was no teacher to explain things
    b. you could not look back at previous materials
    c. you could not correct errors
    d. the computer went too slow
    e. other (please specify)______________________

6. The most desirable feature of the computer was-

    a. it didn't go too fast and leave you behind
    b. you were not embarrassed when you made mistakes
    c. it told you immediately when you were wrong
    d. it was interesting and fun to work with
    e. other (please specify)______________________

7. In general, you feel that the experiment was-

    a. very interesting and enjoyable
    b. satisfactory
    c. a little boring
    d. a waste of class time

Questionnaire for Boolean Algebra Experiment continued.

8. When working on the questions, you-
    - a. always tried to answer correctly
    - b. tried some, but not too hard
    - c. really didn't try as much as you should
    - d. mostly guessed, since it doesn't matter

9. Generally, you found the Boolean Algebra-
    - a. very easy
    - b. fairly easy
    - c. a little hard
    - d. very difficult

10. When answering questions in the material-
    - a. you prefer answering multiple choice questions using the pen
    - b. you prefer answering completion questions using the keyboard

11. Which areas were most difficult for you?
    - a. mathematical logic
    - b. set theory
    - c. switching circuits
    - d. Boolean laws

12. Which areas were easiest for you?
    - a. mathematical logic
    - b. set theory
    - c. switching circuits
    - d. Boolean laws

13. When answering the questions, you-
    - a. generally answered most of them correctly
    - b. missed only a few
    - c. missed most of them, but knew a few
    - d. guessed most of the answers

14. The hints and remarks which followed your wrong answers
    - a. often helped you find the correct answer
    - b. rarely helped you find the correct answer
    - c. were a waste of time

15. How do you feel after finishing the Boolean algebra experiment?
    - a. you understand this material very well
    - b. you were beginning to catch on to the main ideas
    - c. you were not quite sure you understood
    - d. you understand hardly any of it

16. In general, you feel students learn better when
    a. working in pairs
    b. working individually

17. If you had a choice, you would prefer
    a. working in pairs
    b. working alone

18. If you were selecting a partner in a new experiment, you would
    a. choose your best friend
    b. choose someone smarter than you
    c. choose someone with equal ability
    d. it would not matter to you

________19.____(Paired students only)______________________________

If you were going to work in a new pair, would you select the same partner?

a. yes
b. no

20. Which do you consider the best advantage of working with a partner?
    a. partner can explain material to you
    b. partner makes you feel more comfortable
    c. partner means you don't have to work quite as hard
    d. other (please specify)________________________

21. Which of these do you consider the worst disadvantage of working in pairs?
    a. your partner slowed you down
    b. your partner worked too fast
    c. you and your partner disagreed too often
    d. other (please specify)________________________

22. When working together-

    a. you did most of the work while you watched
    b. you both worked about the same amount
    c. your partner did most of the work while you watched

23. If you and your partner disagreed on an answer, usually you-

    a. did what you wanted
    b. did what your partner wanted
    c. tried to work it out together, then answer
    d. gave up and guessed

24. If you were to judge your pair as a learning team, you would rate yourself-

    a. worked together very well
    b. did O.K. together
    c. just managed to get alone
    d. did not work together well

APPENDIX H

STUDENTS PARTICIPATING IN THE STUDY

THIRD PERIOD STUDENTS PARTICIPATING IN THE STUDY

Pairs

1. Beam, Mitchell
2. Braxton, Quentin

---

3. Duff, Vic
4. Tucker, Sonny

---

5. Eubanks, Melissa
6. Moorhead, Nancy

---

7. Fultz, Betty Nell
8. Kilenyi, Ethel

---

9. Gordon, Debra
10. Heath, Lyn

---

11. Hilbert, Mark
12. Lewis, Randy

---

13. Oppenheimer, Donna
14. West, Edwina

---

15. Owens, Regina
16. Smith, Shauna

---

17. Riley, Charles
18. Swartz, Freddie

Individuals

19. Cashin, Mike
20. Clayton, Bev
21. Cole, Jimmy
22. Harold, Margaret
23. Johnson, Daphne
24. McDonald, Lowell
25. Scott, Randy
26. Strickland, Vicki

FOURTH PERIOD STUDENTS PARTICIPATING IN STUDY

Pairs

1. Albertson, Roy
2. Flowers, Woody

3. Chandler, Craig
4. Mitchell, Frank

5. Dunlap, Donnie
6. Graddy, Alan

7. Earle, Eric
8. Ott, Hugh

9. Featherstone, George
10. Langston, Alan

11. Fulford, Lee
12. Sheward, Sheri

13. Herp, Sandy
14. Thorpe, Jean

15. Martin, David
16. Mobley, Melvin

17. O'Brien, Susan
18. Schultz, Diane

Individuals

19. Curry, Katy
20. Gray, Donna
21. Herold, Mary
22. Herp, Susie
23. Hilbert, Rusty
24. McCollum, Judy
25. Poppell, Linda
26. Strickland, Tom
27. Swartz, Jeffry
28. Young, Kimber

APPENDIX I

CONCEPT UNIT SCORES

CONCEPT UNIT 1

	Pairs	Individuals	Total
Preview	2	4	6
Criterion	11	7	18
Quiz	1	4	5
Final	22	10	32
CONCEPT UNIT 2			
Preview	14	13	27
Criterion	11	13	24
Quiz	5	6	11
Final	27	17	44
CONCEPT UNIT 3			
Preview	1	2	3
Criterion	3	3	6
Quiz	9	11	20
Final	25	14	39
CONCEPT UNIIT 4			
Preview	17	16	33
Criterion	17	15	32
Quiz	9	8	17
Final	24	11	35
CONCEPT UNIT 5			
Preview	6	12	18
Criterion	18	16	34
Quiz	12	5	17
Final	21	12	33
CONCEPT UNIT 6			
Preview	13	12	25
Criterion	11	15	26
Quiz	8	9	17
Final	6	7	13

CONCEPT UNIT 7

	Pairs	Individuals	Total
Preview	13	7	20
Criterion	14	6	20
Quiz	10	5	15
Final	24	11	35
CONCEPT UNIT 8			
Preview	9	13	22
Criterion	1	1	2
Quiz	13	14	27
Final	14	11	25
CONCEPT UNIT 9			
Preview	5	0	5
Criterion	3	5	8
Quiz	6	2	8
Final	17	5	22
CONCEPT UNIT 10			
Preview	16	14	30
Criterion	16	15	31
Quiz	15	17	32
Final	34	17	51
CONCEPT UNIT 11			
Preview	4	4	8
Criterion	12	13	25
Quiz	5	9	14
Final	17	10	27
CONCEPT UNIT 12			
Preview	15	14	29
Criterion	17	15	32
Quiz	5	5	10
Final	25	12	37

CONCEPT UNIT 13

	Pairs	Individuals	Total
Preview	4	1	5
Criterion	4	5	9
Quiz	5	6	11
Final	8	6	14

CONCEPT UNIT 14

Preview	4	4	8
Criterion	11	6	17
Quiz	5	5	10
Final	11	9	20

CONCEPT UNIT 15

Preview	3	3	6
Criterion	11	11	22
Quiz	2	3	5
Final	17	9	26

CONCEPT UNIT 17

Preview	1	8	9
Criterion	8	8	16
Quiz	5	4	9
Final	4	4	8

CONCEPT UNIT 18

Preview	8	6	14
Criterion	4	7	11
Quiz	1	4	5
Final	8	3	11

CONCEPT UNIT 20

Preview	12	12	24
Criterion	13	9	22
Quiz	11	12	23
Final	25	11	36

CONCEPT UNIT 29

	Pairs	Individuals	Total
Preview	2	5	7
Criterion	14	11	25
Quiz	2	4	6
Final	27	12	39

CONCEPT UNIT 30

Preview	7	1	8
Criterion	1	3	4
Quiz	5	5	10
Final	18	9	27

CONCEPT UNIT 31

Preview	3	3	6
Criterion	6	8	14
Quiz	2	1	3
Final	8	7	15

CONCEPT UNIT 32

Preview	2	1	3
Criterion	5	6	11
Quiz	6	5	11
Final	21	9	30

CONCEPT UNIT 33

Preview	2	1	3
Criterion	6	5	11
Quiz	10	4	14
Final	17	9	26

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13. ABSTRACT

The use of paired learning teams was investigated as a possible technique for improving instructional achievement and efficiency. The primary question was the comparison of achievement of students who learned in pairs with the achievement of students who learned individually, all subjects being tested independently and instruction presented by means of an IBM 1500 CAI system. Fifteen subsidiary questions were investigated including comparison of error rates, various timing measures, and confidence ratings. Also investigated were the pair-formation variables, the nature of paired interaction, and variations of task difficulty.

Fifty four basic algebra students were divided into 18 pairs and 18 individuals, where paired partners were selected by mutual choice. The two groups took a five lesson Boolean algebra program at the Florida State University CAI Center in the Spring of 1969. The program included a basic

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introduction to logic, set theory, and switching networks which were divided into 23 concept "units." A preview question was given at the beginning of each concept unit, a criterion question at the end of the unit, a daily quiz was at the end of each lesson, and a final examination after completion of the program.

A comparison between the paired group and individual group on final examination scores revealed no significant differences in achievement. No differences were found on any of the seven time variables recorded although the paired group required less time on six of these measures. No differences were found in error rates, number of practice problems solved, criterion frame scores, or daily quiz scores. No differences were located between "successful" pairs and the individuals or the "other" pairs.

In conclusion, with instruction presented by CAI, the paired group learned Boolean algebra as well as the individuals in every respect. In addition, with two students instead of one at each CAI terminal, educational costs may be substantially reduced and system efficiency increased.